

Note that the times shown in the study plan overleaf do not include the time that you will need to answer questions on the DVD and the TMA, making use of the set book, watching the TV programme, attending sessions at your local or regional centre or reflecting on what you have learned and how you have learned it. Past students have also commented that *our* estimates of the times needed for the study of the DVD-multimedia activities are likely to be low.

Study Guide for Block 10

Block 10 is a wide-ranging look at the Earth, its rocks and the history of its life through geological time, and continues our quest of 'putting the world together'.

In Section 2, we see how organisms can get preserved as fossils, and then we look at some key events in the early evolution of life. In Section 3 we study the invasion of life onto land, extinction — the natural fate of nearly all species, and evolutionary radiations. The fossil replicas in the Practical Kit are used in two major practical work activities (Activities 2.1 and 3.1). These will help you to develop the important skills of making and recording observations of three-dimensional specimens, and of interpreting aspects of the biology and environment of ancient organisms.

In Sections 4 to 7 we continue the study of rocks begun in Block 3. In Section 4, minerals — the building blocks of rocks — are mainly explored in two DVD-multimedia activities. You will find it convenient, though not essential, to study the main text in conjunction with the DVD material.

In Section 5 we look at igneous rocks and at some of the processes involved in the formation and crystallization of magma. This is probably one of the more difficult areas of the block, but it will enable you to understand why there is such a diversity of igneous rocks. Sedimentary rocks and their formation are discussed in Section 6, where an activity involving a DVD-video sequence ('A story in sand') supports the discussion of processes such as weathering, erosion and deposition. You will also investigate sedimentary processes first hand by doing a short practical activity that uses soil as the sedimentary material. The main requirements for this activity are a sample of soil, and a jar or bottle made from clear glass or plastic, with a tight-fitting lid. In Section 7, we study metamorphic rocks and the settings that produce them. There are several activities in Sections 5–7 that will involve you revisiting briefly the rock specimens in the Practical Kit, and these will develop further the skills introduced in Block 3 of observing, recording and interpreting different types of rock.

Section 8 explains how we can date rocks (and their fossils) in absolute terms, and then in Section 9 we look at some scenes from Britain's eventful geological past. The DVD-multimedia activity 'A geological field trip' explores evidence that about 275 million years ago Britain experienced a climate as hot and dry as the Sahara Desert today. The skills you develop here will complement the experience you will have of looking at natural exposures of rocks in the field if you register for SXR103 *Practising Science*. Finally, in Section 10, we broaden the perspective still further and look at just a few of the intimate connections between the solid Earth, its oceans, its atmosphere and its life.

This block represents three weeks' work. The study plan overleaf shows how you might divide your time over the three study weeks. However, if you have chosen to omit study of either Block 9 or Block 11 you may wish to spend a little more time on Block 10. You will need to allocate additional time for the DVD questions on this block, for the TV programme, attending study centre sessions and for the assignment; TMA 08 is associated with Block 10. The *Study Calendar* gives you the broadcast time of the TV programme 'Lost worlds', which is mainly about extinction; it relates most closely to Section 3.

If you have chosen to omit study of Block 9 then we *recommend strongly* that you attempt the supplementary activities in the Appendix to the Study File for Block 10. These will help you to develop your skills at answering assignment questions and provide practice in writing longer accounts.

We recommend that you study the various sections of this block — including the DVD-multimedia activities — in the order in which they are presented, as the sections often build on material covered in earlier sections.

10 Earth and life through time

All study times are in hours

Week	Sections of Book 10	Total study time	DVD-multimedia, DVD-video and practical activities
1	1 Introduction	$\frac{1}{4}$	
	2 Fossils and the early history of life	4	 $1\frac{1}{2}$
	3 More of life's comings and goings	$4\frac{1}{2}$	 1
	4 Minerals — the crystalline world	$2\frac{1}{2}$	 $1\frac{1}{2}$
2	5 Igneous rocks — out of the melting pot	$3\frac{1}{4}$	 $\frac{1}{4}$
	6 Sedimentary rocks — recording surface environments	4	 $\frac{1}{4}$  $\frac{3}{4}$
	7 Metamorphic rocks — taking the heat and the pressure	2	 $\frac{1}{4}$
3	8 Geological time	$2\frac{3}{4}$	
	9 Scenes from Britain's geological past	4	 1
	10 Connections	$2\frac{3}{4}$	
	'Lost worlds' should be viewed at any time after you have completed Section 3.		

Study File for Block 10

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Notes on activities

You should read through the notes for each activity before attempting it. After completing an activity you should study the relevant comments in the next section of the Study File.

No estimate of time is given for activities that should take 10 minutes or less.

Activity 2.1 Life in the Silurian sea

(The estimated time for this activity is 1 hour 30 minutes.)

Aims

- 1 To examine and interpret the features of three fossil replicas, in order to understand aspects of the biology of the species represented, and to use this evidence to reconstruct the environment in which they lived.
- 2 To develop the practical science skills of observation and recording of information from three-dimensional objects, using annotated drawings.



Equipment

KIT ITEMS
fossil replicas A, B, C
hand lens

NON-KIT ITEMS
pencil, ruler, eraser
Block 10

Introduction

As we've seen, the Cambrian explosion left the seas teeming with a huge variety of animals. In this activity you will study some of the marine life at one particular time in the Palaeozoic Era — the middle part of the Silurian Period, 430 Ma ago. You'll look at three fossils (A, B and C), which come from a deposit in the UK called the Wenlock Limestone, famous for its many beautiful fossils. The Wenlock Limestone outcrops mainly around Birmingham and the borders of Wales.

The ability to make accurate observations is the most fundamental skill in any science, and for Earth sciences there is no better training than studying three-dimensional objects such as rocks, minerals and fossils, and making drawings to record your observations. The replicas of fossil specimens in the Practical Kit will help you to continue to develop these observational skills, and train you to make inferences about the biology, mode of life and environment of extinct species.

Important advice

There is no need to spend ages on your drawings. Use simple lines and avoid elaborate shading.

Sometimes, a few small gas bubbles (now round holes) may have become trapped during the making of a replica; if so, please ignore them.

When using a hand lens, you should ensure that the specimen is well lit, with the light over your shoulder, and bring both the hand lens *and* the specimen up as close to your eyes as is comfortable for focusing.

If you have not already labelled the six fossil replicas with the letters A–F, you should do so by referring to Figure 1 of the *Practical Work Booklet*.

Practical procedure

Task 1 Observations of fossil A

Take the replica of fossil A and examine it for a minute or so, first with the naked eye, and then with your hand lens.

Fossil A is a trilobite (pronounced ‘try-lo-bite’). Trilobites were a major group of entirely marine arthropods that thrived in the seas of the Palaeozoic Era and eventually became extinct in the Permian Period. The arthropods, as we saw in Block 4, Section 5, are an immensely diverse phylum that also includes crabs, lobsters, insects, spiders and scorpions. They have an external, jointed skeleton that forms a rigid casing for the body, though it is flexible over the joints to allow movement. Trilobites, like other arthropods, grew by moulting, i.e. periodically casting off their rigid outer shell, and secreting a new, larger one.

Trilobites are so named because they have three lobes running along their length — a central axis, and two lobes on either side. They are also divided cross-ways into a headshield, a trunk, and a tail region. Have a preliminary look at fossil A to see if you can identify these divisions. The tail region is made of a single plate (the tailpiece). Trilobites also had appendages such as antennae and legs, but these are extremely rarely found.

- ☐ What does the rarity of fossil trilobite appendages suggest about their structure?
- ☐ They were not so durable, being less mineralized than the components normally found (headshield, trunk and tailpiece), and soon decayed like other soft tissues.

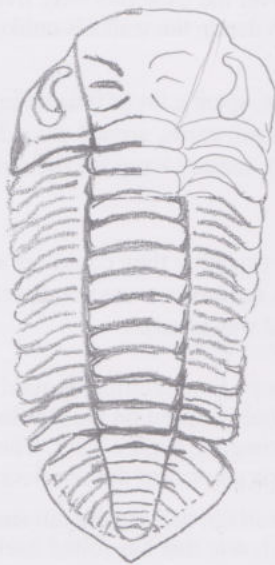
Now finish the partially completed drawings of this fossil in Figure 2.1.1, using your hand lens to observe the details. There are two views of the fossil at the same scale, one from above (a) and one from the right-hand side (b). Draw a scale bar (like that on Figure 2.1.2) to indicate the extent of a centimetre on the specimen. *Remember: do not spend ages on your drawings; just use simple lines and avoid fancy artistic impressions.* Label your drawing of trilobite A with its generic name, *Acaste* (‘ay-casty’).

Study Figure 2.1.2, which shows another trilobite from the Wenlock Limestone, called *Calymene* (‘kal-iminny’). You should decide which labelled parts of *Calymene* correspond to those of *Acaste*, and then label your completed drawings of *Acaste* accordingly with the same terms (i.e. headshield, etc.). Both the replica and Figure 2.1.2 represent full-grown adults.

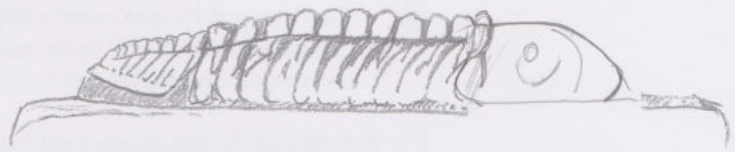
- ☐ Which has more trunk segments, *Acaste* or *Calymene*?
- ☐ *Acaste* has 11 segments, *Calymene* has 13. If you got this wrong, look again; you may have misidentified where the trunk begins and ends. Label the number of trunk segments on Figure 2.1.1.

Because trilobites cast off their shell during moulting, most trilobite fossils are actually shed shells, rather than carcasses (dead animals). The trilobite’s hard outer shell needed places of weakness along which it could break apart during moulting, a bit like the weak areas between the pieces of a bar of chocolate. There were zones of weakness between the headshield and the front of the trunk; between any two trunk segments; and between the end of the trunk and the front of the tailpiece.

- ☐ Do you think it more likely that fossil A is a carcass or a moult?
- ☐ It is more likely to be a carcass than a moult because the skeleton is not split up into separate pieces.



(a)



(b)

Figure 2.1.1 Fossil A from above (a), and from the right-hand side (b). The blank areas are to be drawn in.

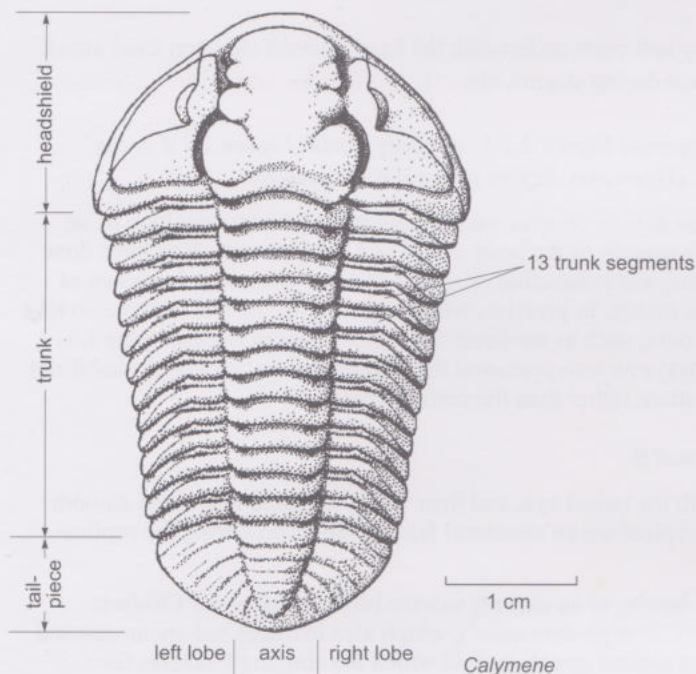


Figure 2.1.2 *Calymene*, a trilobite from the Wenlock Limestone.

- Use your hand lens to look at one of the two crescent-shaped, upstanding areas on either side of the head of fossil A. What structures do you think they represent?
- They are eyes!

The tiny bumps arranged in rows on each crescent are, amazing as it may seem, the lenses of an eye. The eyes were rather like those of a modern fly (another arthropod) in having many lenses. Each trilobite lens was made of calcite, and its preservation potential was as good as the rest of the skeleton (also made mostly of calcite). Trilobites had the earliest known eyes in the animal kingdom. Label the eyes of *Acaste* and of *Calymene*.

- Try to estimate the number of lenses in an eye of *Acaste*, but *without* counting them all. Here's a choice: is the number of lenses nearest to 10, 50, 100 or 200 lenses?
- There are about 100 lenses in each eye. (As the lenses are evenly spaced, you could have counted say, about a half, or a quarter of the eye surface, and then multiplied up.)

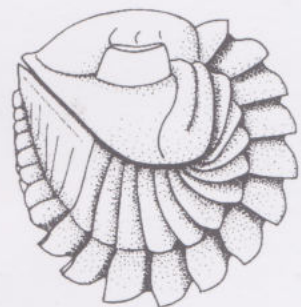


Figure 2.1.3 Drawing of a fossil *Acaste* that has rolled itself up into a ball.

The presence of well-developed eyes suggest that wherever the trilobites were living there was enough light to see by, and, as light fades with depth, the water is unlikely to have been very deep.

- Trilobites that, according to independent evidence, spent a lot of time swimming well above the sea floor had eyes that extended downwards, around the side of the head, and onto the underside. Is this the case with *Acaste*? Examine the directions that its lenses are facing.
- No. Although its eyes cover a large field of view (together they could see around a complete circle of 360° in the plane of the body), the lenses were not directed downwards and underneath (except when its head was tilted).

It is therefore likely that *Acaste* (and *Calymene*) spent more time scuttling around on the sea floor than swimming high up in the water. They probably rested on the sea floor, stretched out in the same way as in fossil A and the specimen in Figure 2.1.2. These trilobites probably ate small organisms and organic debris on or near the sea floor.

Some trilobites, including *Acaste* and *Calymene*, could roll up, tucking the tail snugly underneath the head. Figure 2.1.3 shows a specimen of *Acaste* that has rolled itself up into a ball, as woodlice (also arthropods) can do. The flat, outer edges of the trunk segments, which can be observed on the out-stretched fossil A, had to slide over each other to enable the trilobite to roll up.

- Why might the ability to roll up be useful?
- It would protect any soft parts underneath the hard external skeleton from attack by predators, damage during storms, etc.

Finally, to check your completed Figure 2.1.1, compare it with Figure 2.1.6 in the comments on this activity. (Yours may be just as good if not better!)

In summary, you have been able to observe various features of the morphology of an extinct organism, and infer aspects of its mode of life and environment. You have done this by making observations, and comparing observed features with what is known of living relatives and similar fossils. In practice, when studying fossils one would also take other information into account, such as evidence from the sediment enclosing the fossil, and so on. The result is always an *interpretation* that reflects the balance of probabilities from the available information, rather than the certain truth.

Task 2 Observations of fossil B

Examine fossil B, first with the naked eye, and then with your hand lens. (The smooth sides near the base of the replica are an unnatural feature produced during the replica-making process.)

Fossil B is a coral. Corals belong to an entirely marine phylum called the Cnidaria (pronounced with a silent 'C': 'nigh-dare-ee-a'), which also includes sea-anemones and jellyfish. Cnidarians have a central mouth around which are stinging tentacles for catching tiny prey. Sea-anemones and jellyfish are soft-bodied, but corals secrete a skeleton below the soft, anemone-like parts at the top.

Now finish the partially completed illustration of fossil B in Figure 2.1.4. Again, there is no need for any time-consuming shading, etc.; just use simple lines. Draw in a scale bar to show the extent of 1 cm.

Some corals, such as fossil B, form colonies of genetically identical individuals that share a complex skeleton; others are totally separate individuals, resembling isolated sea-anemones. When alive, fossil B would probably have looked like a bunch of sea-anemones, with each of them sitting in one of the bowl-shaped hollows. The skeleton secreted by an individual in a colony is called a corallite, and the corallites share adjacent walls. Each corallite is divided by a series of radial partitions.

- Look at some of the more central corallites in fossil B. How many *other* corallites is any one corallite surrounded by?
- It varies a little, but most corallites are surrounded by about five others.

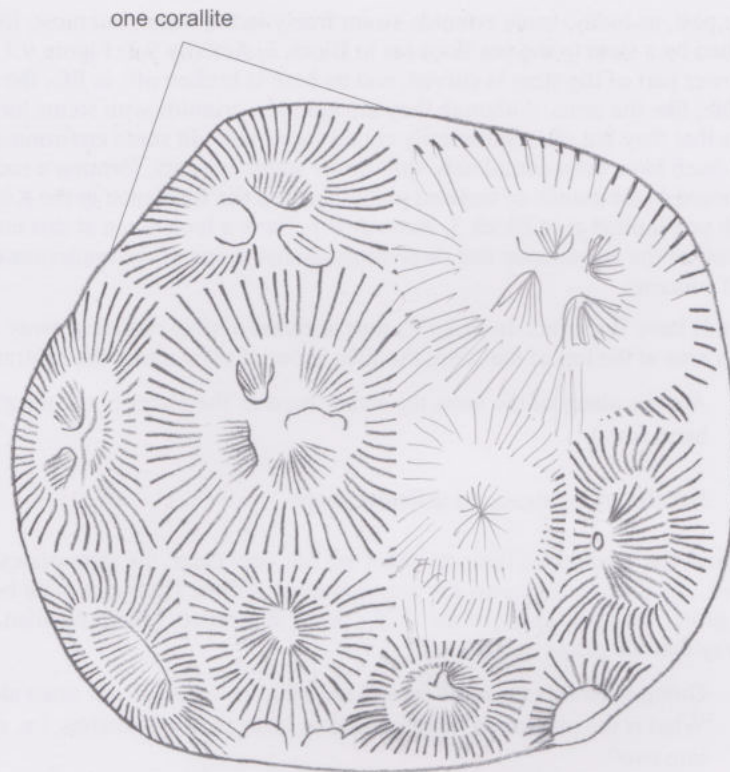


Figure 2.1.4 Partially completed illustration of fossil B, in plan view.

In the centre of some corallites there is a single bowl-shaped hollow; in the larger ones, the central area is divided into several smaller hollows. Look again with the hand lens at the central parts of the two corallites that you drew in Figure 2.1.4. Each of the five little hollows in the larger of these corallites has the same basic structure of radial partitions. These little hollows are *new* corallites that have budded off their parent, enabling the coral to grow upward and outward by a process of asexual reproduction. As the offspring grew to full size, the parent corallite eventually decayed.

Now label on Figure 2.1.4 these parts of the coral colony's skeleton we have mentioned: *radial partition*; *bowl-shaped hollow*; *newly budded corallite*.

- What sort of environments are corals associated with today?
- Images of Australia's Great Barrier Reef and tropical islands such as the Bahamas probably spring to mind.

Most, but not all, corals today grow in warm, clear, shallow seas. The same seems to have been true of many ancient corals, especially the colonial ones. The requirement of many of today's corals for clear, shallow water is mostly because within the corals' soft tissues are tiny algae with which they live in an association of mutual benefit. The algae require good access to light for photosynthesis.

If you wish to check your completed Figure 2.1.4, compare it with Figure 2.1.7 in the comments on this activity.

Task 3 Observations of fossil C

Again, examine fossil C first with the naked eye, and then with your hand lens.

- Given that this organism is composed of many calcite plates, and is related to starfish and sea-urchins, to which phylum does it belong?
- It belongs to the phylum Echinodermata (described in Section 2.2).

Fossil C is a type of echinoderm called a crinoid ('cry-noyed'). Although crinoids occur today, they were far more common in the Palaeozoic and Mesozoic Eras. Most crinoids feed by bending their umbrella-like arrangement of appendages (called 'arms') towards a current. Tube-feet (the multi-purpose tentacles) on the arms gather food particles suspended in the water, which are then wafted by small hair-like threads along the arms to the central mouth. Most ancient crinoids lived gregariously in shallow, current-swept areas, free of muddy sediment that would otherwise clog their feeding mechanism.

In the past, as today, some crinoids swam freely in the water, but most, like fossil C, were attached by a stem to the sea floor (as in Block 3, Activity 9.1, Figure 9.1.3). In fossil C, the lower part of the stem is curved, and its base is broken off: in life, the stem was fairly flexible, like the arms. Although they are animals, crinoids with stems look at first so like plants that they are often informally called 'sea-lilies'. In some environments, crinoids after death have been completely split up by water currents, forming a rock largely composed of thousands of isolated plates, such as the limestone in the Kit (specimen 3), which you looked at in Block 3, Activity 9.1. Have a look again at this now, to remind yourself of the appearance and three-dimensional shape of the numerous crinoid plates that it contains.

Crinoids have five arms. In fossil C, four arms are visible radiating away from the central mouth area at the top of the stem; the fifth is out of view under the central area.

- ☐ Are the plates of the arms the same shape as the plates of the stem? (Use your hand lens.)
- ☐ No, the arm plates are a different shape.

Although the boundaries between them are not very clear, the stem plates are disc-shaped, and those of the arms are jug-shaped in outline. Each arm plate bears one or more little projections (the spout of the 'jug'). Such differences reflect detailed differences in the way that the plates functioned.

- ☐ Going outwards from the central mouth area, follow a few arms along their length. What is the maximum number of times that an arm branches, i.e. splits from one into two?
- ☐ Some arms branch as many as five times.

With this branching pattern, the animal was able to keep the distance between its arms approximately constant as it grew outwards, and this maintained an efficient food-gathering arrangement throughout its life.

Draw in the plates near the bases of two arms in the small blank area of Figure 2.1.5. Then label the following parts: *calcite plates*; *branching arms*; *base of an arm*; *central mouth area*.

Task 4 Synthesis of information about the Wenlock Limestone environment

Now let's review what information the study of fossils A, B and C has yielded about the environment in which the Wenlock Limestone was deposited. (All three types of fossil are common in the Wenlock Limestone.) In answering the following questions, you should state briefly the relevant evidence or reasoning.

- (a) Was it a marine or freshwater environment?
- (b) What was the water depth, in qualitative terms?
- (c) Was the water usually still and free from currents?
- (d) Was the water normally clear or muddy?
- (e) Was the water warm or cold?

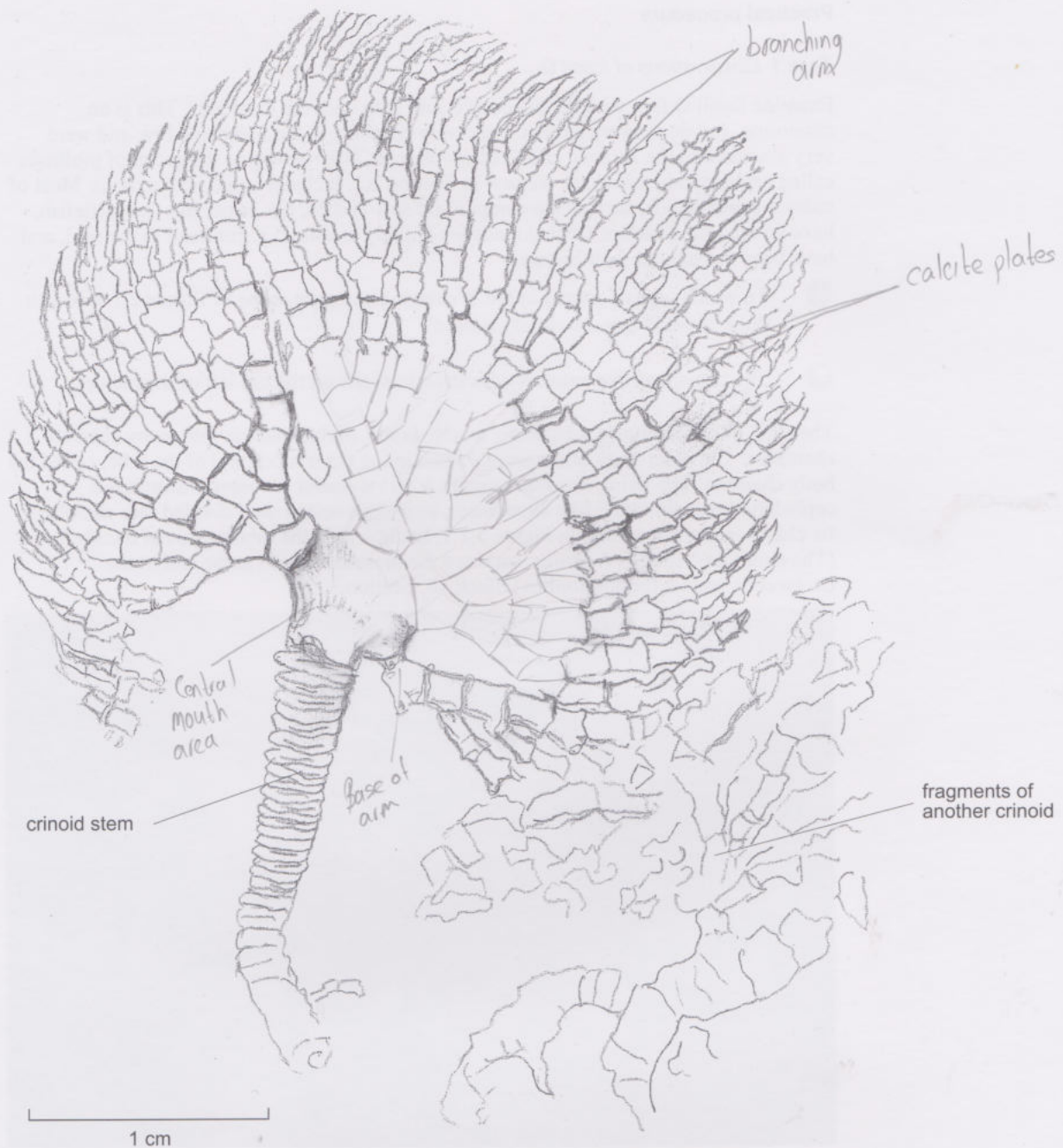


Figure 2.1.5 Partially completed illustration of fossil C, in plan view.

To check your completed Figure 2.1.5, compare it with Figure 2.1.8 in the comments on this activity.

Activity 3.1 Life in the Jurassic sea

(The estimated time for this activity is one hour.)

Aims

- 1 To examine and interpret the features of three fossil replicas, in order to understand aspects of the biology of the Jurassic species represented.
- 2 To develop the practical science skills of observation and recording of information from three-dimensional objects, using annotated drawings.

Introduction

The second group of Practical Kit fossils come from the shallow seas of the Jurassic Period, and are about 270 Ma younger than those you studied in Activity 2.1. Fossils D, E and F were found in different places in southern England, and they were alive at different times within an interval from about 165 to 155 Ma ago.



Equipment

KIT ITEMS
fossil replicas D, E, F
hand lens

NON-KIT ITEMS
pencil, ruler, eraser
Block 10

Practical procedure

Task 1 Observations of fossil D

Examine fossil D first with the naked eye, and then with the hand lens. This is an ammonite. Ammonites are extinct; they were confined to the Mesozoic Era, and were very abundant in the Jurassic and Cretaceous seas. They belong to the group of molluscs called cephalopods, which, as we saw in Section 2.2, includes squid and octopus. Most of today's cephalopods, such as the octopus, are soft-bodied, but some, like the cuttlefish, have an internal skeleton. Cephalopods are entirely marine (i.e. confined to the sea), and have been throughout their history.

- To which type of animal in the Wenlock Limestone scene of Figure 2.1.9 do you think fossil D is most closely related?
- The two squid-like animals with straight shells on the top left of the picture.

The shell of an ammonite is basically a coiled tube, divided across into many separate chambers. The main body of the animal lived in the outer, open end of the tube, called the body chamber. The living *Nautilus* (Figure 3.1.1) is useful for comparison; it is a cephalopod, which, rather like ammonites, also has a coiled shell divided into chambers. Its chambers are not visible in Figure 3.1.1, being within the tubular part of the shell. (The nautiloids, such as *Nautilus*, survived the mass extinction at the end of the Cretaceous, unlike the ammonites (Block 10, Section 3.2).)



Figure 3.1.1 A living *Nautilus*. The tentacles, eye and other soft parts can be seen, as well as the shell. The chamber walls *cannot* be seen in this external view.

- Which part of the *Nautilus* and ammonite shells do you think grew first, when the animals were very young?
- The centres of their shells.

As the ammonite grew, it extended its tubular shell, and moved its body on outwards, laying down a new chamber wall behind it. The earlier-formed chambers contained a mixture of gas and water by which the animal adjusted its buoyancy. After an ammonite died, the chambers usually became punctured and filled with sediment, as in fossil D.

The chamber walls of ammonites are highly complex in shape. Where each wall meets the tubular part of the shell it shows up as a highly intricate frilled pattern if the tubular part of the shell has been dissolved away (as is the case in fossil D), or if it has peeled off. Look at fossil D with the hand lens; you should be able to see these frilled patterns crossing the shell. Each one looks a bit like the intricate margin of a leaf, such as that of a fern. The distance between equivalent points on two successive chamber walls is about 2–5 mm, depending on where the measurement is made.

- How far back towards the central, first-formed part of the shell can you see the frilled patterns that indicate the chamber walls? Use your hand lens.

- They can be detected right back almost to the centre.

To find exactly where the body chamber begins on fossil D, examine the shell as it spirals outwards. You will see that eventually the chamber walls stop, and you don't find another one where you would expect it from their previous spacing. On this specimen, most of the body chamber is missing: having an open end, it was easily crushed.

The shell is covered by a series of ridges (each far simpler in shape than that of a chamber wall): there are long ones that cross the tube, and sometimes divide into two, and shorter ones that appear only about half-way across.

- Look at the pattern of these ridges. Is there a constant number of shorter ridges between the longer ones?
- No. The number of shorter ridges between the longer ones varies.

The net result is, however, that, along the outermost edge of the shell (i.e. farthest from the centre), the ridges are evenly spaced: check this for yourself. The ridges may have helped to stabilize the animal in currents or as it propelled itself through the water.

Now label on Figure 3.1.2a these parts: *start of body chamber* (i.e. the last chamber wall to be formed by the animal); *complex chamber walls*; *ridge*; *first-formed part of shell*.

The ammonite shell has a single plane of symmetry that divides the shell into two equal parts. Only one half of the ammonite shell is visible on the replica; the other half — the mirror image on the other side of the plane of symmetry — lies (in effect) in the base of the replica. Knowing this, use the blank space in Figure 3.1.2b to make a rough drawing at true scale ($\times 1$) to show the shape of the *whole* shell when viewed looking towards the body chamber *along the plane of symmetry*. Place the body chamber at the bottom, as it would have been in the life of the animal (as in *Nautilus*, Figure 3.1.1). *Don't worry about drawing in more than four or five ridges* — concentrate on the general outline of the shell.

Ammonite shell shapes varied greatly; those with fatter profiles in cross-section would have presented a greater resistance to motion in the water; sleek ones are thought to have been adapted for faster motion.



(a)

1 cm



(b)

Figure 3.1.2 (a) A plan view of fossil D; (b) space for you to draw the outline of the *whole* shell viewed along its plane of symmetry (see text).

To check your completed Figure 3.1.2, compare it with Figure 3.1.5 in the comments on this activity.

Task 2 Observations of fossil E

This animal belongs to a separate phylum that we have not mentioned before — the Brachiopoda. Brachiopods (pronounced 'bracky-o-pods') are an entirely marine group of organisms that were highly abundant and diverse in the past, especially in shallow seas during the Palaeozoic and Mesozoic Eras. They are very common in the Wenlock Limestone (discussed in Activity 2.1). Living ones are, however, much rarer today; there are only a few species around the British Isles, for example, where they tend to live in fairly deep water. Inside the valves there are muscles that open and close the shell, and a feeding device that filters out tiny organisms from the water. Note that although brachiopods have two valves, the term 'bivalve' refers specifically to members of the Class Bivalvia within the Phylum Mollusca.

- In bivalve molluscs, such as cockles and mussels (Section 2.2), the plane of symmetry runs *between* the valves of the shell, which are *equal* in size. Is this also the case with this brachiopod, fossil E? Note that the larger of the two valves is mostly hidden in the base of the replica.
- No, in this, as in all brachiopods, the plane of symmetry runs mid-way *through* the two valves, which are *unequal* in size.

Most brachiopods spend their lives attached to the sea floor by means of a fleshy stalk, which rots away after death. The stalk is fixed to a rock or shell fragment, and enables the shell to swivel with the current. The hole near the apex of the larger valve in fossil E is where the fleshy stalk projected through the shell and attached it to the sea floor. The shell hinged open and shut along the junction between the two valves, quite near the hole for the stalk.

- Look at the growth lines on the shell's surface, which represent the edges of the shell at successive stages in its life, and so record its growth history. (Only a few growth lines are conspicuous on the replica.) Where do you think is the part of the shell that formed first, when the animal was very young?
- The first-formed part of the shell is where all the growth lines meet, near the apex.

Several features, including growth lines, are already labelled on the sideways view in Figure 3.1.3a. Now add these labels: *hole for stalk*; *first-formed part of shell*.

- Look at one of the most prominent growth lines on the smaller valve, formed when the shell was about half its current size. Would this valve have had the same shape then as it does now?
- The valve (and the whole shell) would have been relatively wider in comparison to its length at this stage, becoming more elongate later in life.

Draw, to the same scale as in (a), a plan view of the shell in the space in Figure 3.1.3b, placing the pointed end of the shell at the top of your drawing, in line with the plane of symmetry indicated. Finally, label on your drawing in Figure 3.1.3b all six parts now labelled on Figure 3.1.3a.

To check your completed Figure 3.1.3, compare it with Figure 3.1.6 in the comments on this activity.

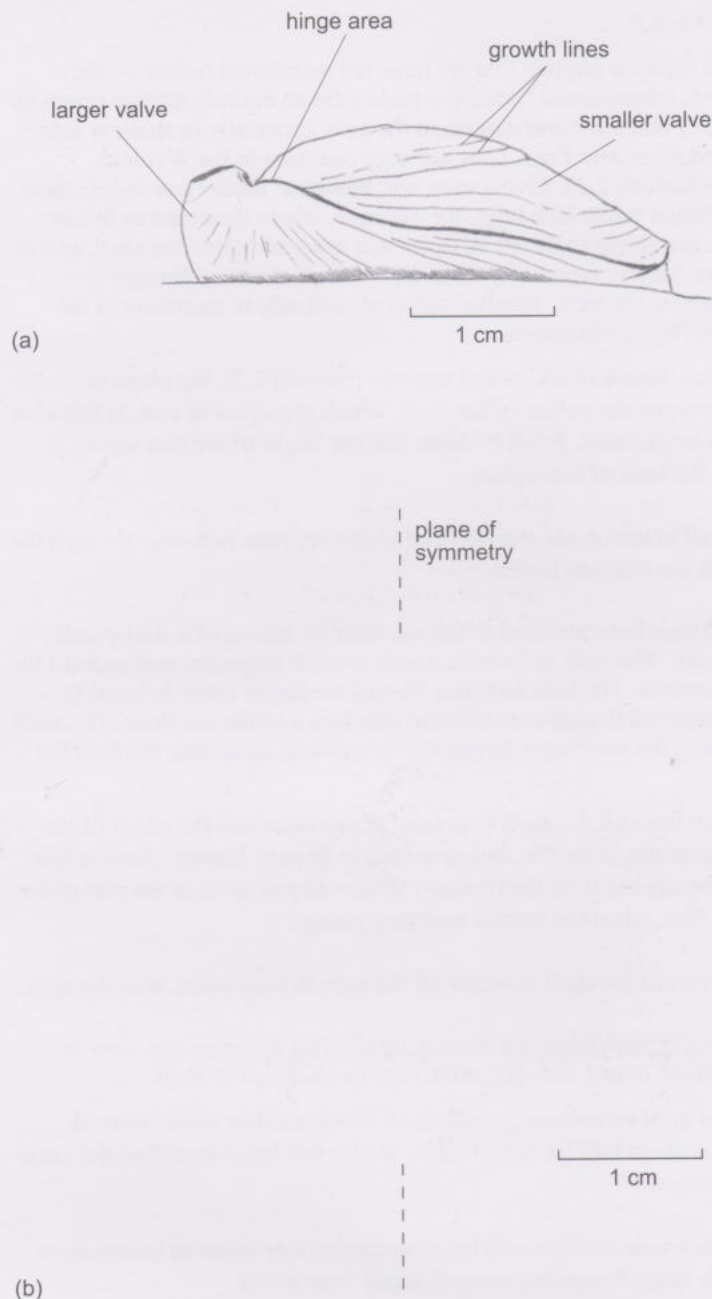


Figure 3.1.3 (a) A side view of fossil E; (b) space for your drawing of fossil E in plan view.

Task 3 Observations of fossil F

Examine fossil F first with the naked eye, and then with the hand lens.

Having already read the description of echinoderms in Section 2.2, and seen Figure 2.6, you should not have had too much trouble recognizing this as a sea-urchin. (If you did, read this part of Section 2.2 again.)

In fossil F there are five paired rows of conspicuous plates carrying large knobs for the attachment of spines. The pores for the tube-feet are located in the five flatter areas between these spine-bearing plates, but the pores, and the boundaries between individual plates, are hard to discern in this case, so don't worry if you can't see them.

- ☐ To which of the other Practical Kit fossils is fossil F most closely related?
- ☐ Fossil C, which is also an echinoderm.
- ☐ Referring back to the description of sea-urchins in Section 2.2, where would you expect the mouth to be? Is fossil F likely to have been a burrower?
- ☐ The mouth is located on the flat underside (but it is not visible in this replica). Most burrowers are oval or heart-shaped; this specimen is round so it is unlikely to be a burrower.

Draw what you can observe at the top of the sea-urchin in the small blank area in Figure 3.1.4a. Use your hand lens.

At the centre of the area you have drawn is a circular depression where the animal expelled wastes through a membrane (no longer present). Immediately surrounding this circular area is a series of five small plates making up a five-sided shape. (Don't worry if you can't see the boundaries between the plates; they are hard to discern.) Each of these plates had a hole in it (not discernable in the replica) through which eggs or sperm were released into the water. One of these plates, larger than the rest, also had tiny perforations through which seawater could enter the internal hydraulic system linking up the tube-feet to other water-filled structures inside.

Usually the spines fell off and dispersed after death, but in their absence (as in fossil F), the size of the attachment knobs gives a good indication of their size. Figure 3.1.4b shows two other fossils of the same species with many of their long, solid spines still attached; the spines were used for locomotion, defence and anchorage in the rough, shallow waters that this species favoured.

Now use your hand lens to examine in detail one of the large protrusions that once carried a spine. In the centre is a ball joint that fitted into a shallow socket at the base of the spine. Muscles operating the spine were attached to the smooth area flanking the central ball joint. By comparing the detailed features of these spine-bearing plates with those of *modern* sea-urchins, much can be deduced about how the spines were held and moved in fossil species.

Now label your completed Figure 3.1.4a: *ball joint for base of spine*; *area for muscle attachment*; *site of waste emission*; *plates through which eggs or sperm released*.

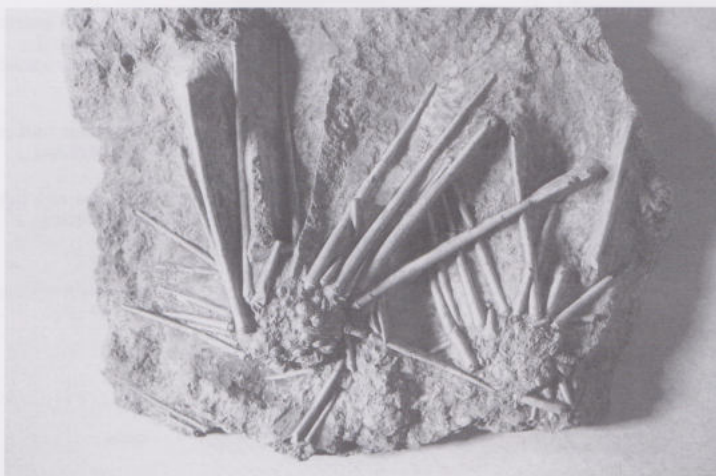
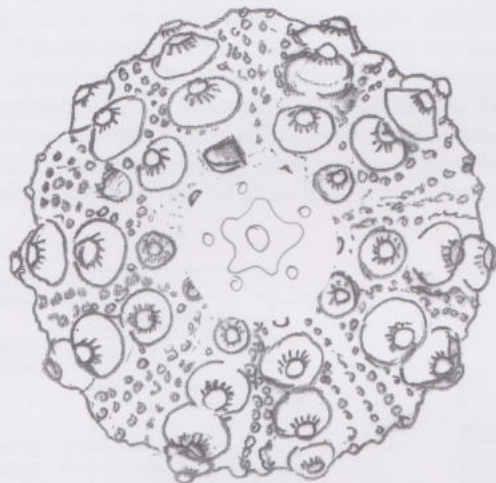


Figure 3.1.4 (above) A plan view of fossil F with blank area to be drawn in; (below) two other fossils of this species with some spines still attached.

To check your completed Figure 3.1.4, compare it with Figure 3.1.7 in the comments on this activity.

Note that, although these three fossil replicas (D–F) all represent Jurassic species, and in each case they indicate a marine environment, each was living at a different time in the Jurassic Period. To reconstruct further details of the environment in which each one lived we would need to study more evidence from other fossils and the particular sedimentary rocks containing them.

Activity 3.2 Matching up rocks — when it's age that matters

Figure 3.2.1 shows columns of rock from two localities, A and B, that are some distance apart, and indicates some of the fossils found in particular (numbered) beds. The thicknesses of different rock types making up each column have been drawn to the same scale, so, for example, bed A2 is thicker than bed B2. Note that it is usually best to consider such a geological column in chronological order, i.e. from the bottom upwards.

(a) Draw dashed lines between the two columns, linking the tops and bottoms of beds that you think were probably laid down at approximately the same time, on the basis of their fossil content.

(b) Write the initial letter of the appropriate era beside the strata on the right-hand side of column A, and on the left-hand side of column B, using P for Palaeozoic, M for Mesozoic and C for Cenozoic. (*Hint:* To work out the era in which the strata were deposited, concentrate on the geological time-ranges of trilobites, ammonites, plesiosaurs and mammals. You may need to refer to Activities 2.1 and 3.1 and Section 3 of the book to remind yourself of this information.)

(c) Where are there unconformities within the succession in each column, i.e. levels representing time gaps when no sediment was preserved for a long interval? There is certain to be an unconformity where rocks of an entire era are missing between successive beds, or where the vertically adjacent rock types are such that there must be a large time gap between them. In such cases, draw a thick horizontal wavy line across the appropriate level in each column and write the letter U for 'unconformity' beside it. Where vertically adjacent beds are from different, although *successive*, eras, indicate the possibility of an unconformity between them by drawing a horizontal wavy line across the appropriate level in each column and write U? for 'possible unconformity' beside it.

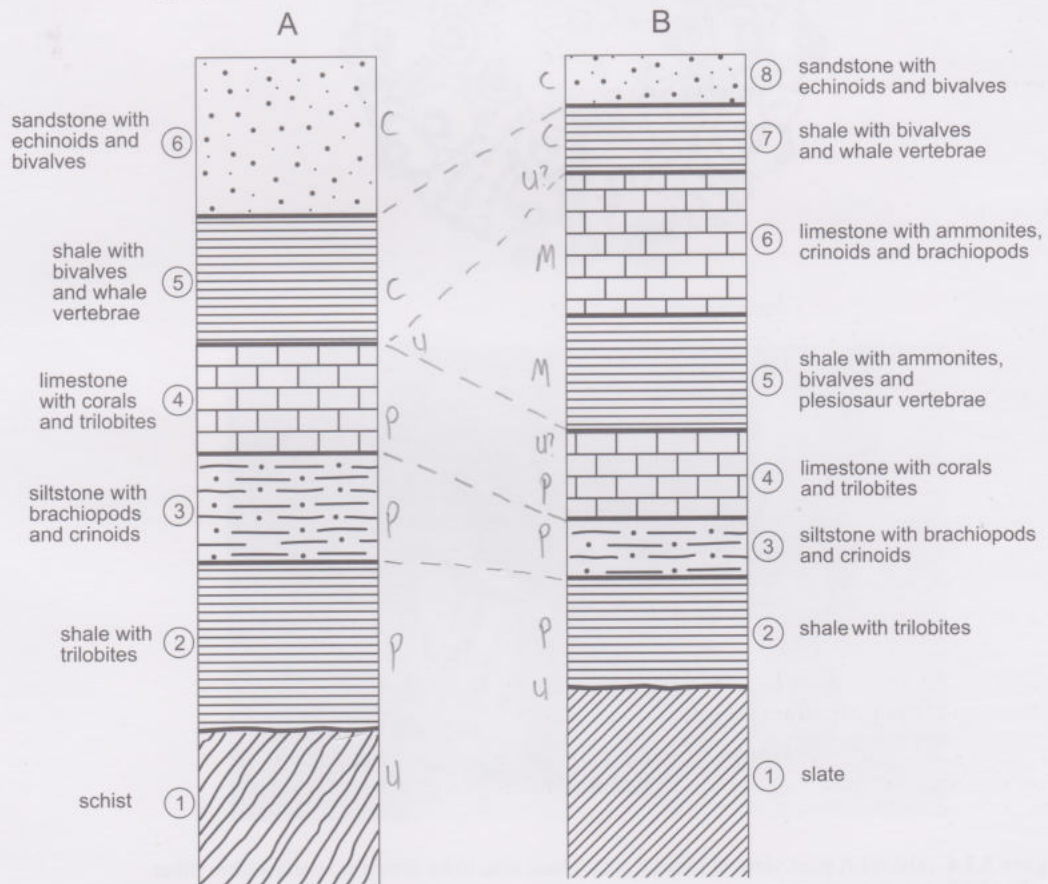


Figure 3.2.1 Columns of rock from two localities, A and B, with rock type and fossil content indicated.

Activity 4.1 Properties of minerals



(The estimated time for this activity is 45 minutes.)

This DVD-multimedia activity introduces six important properties that can be used to distinguish different minerals. Each of these properties is defined, and illustrated with examples, and the structural origins of the property are discussed.

Your main aims as you work through this activity should be to familiarize yourself with the six properties — colour, shape, lustre, hardness, cleavage, and acid test — and with how they can be used to help to identify a specimen of an unknown mineral. You should look for examples of minerals that have (a) well-developed cleavage, (b) different hardnesses, (c) different crystal shapes. You should use the information on the DVD to answer the questions below. You may wish to study the DVD material first and then use the questions to assess your understanding of the material. Alternatively you could take the questions in turn, and use them to guide your exploration of the DVD material.

Question 4.1.1 Many minerals show stunning colours. Why is colour generally not a reliable way of distinguishing between different minerals?

many minerals can have a range of colours depending on the impurities

Question 4.1.2 What are *ferromagnesian* minerals? What colours are these minerals?

silicate minerals containing large amounts of iron or/and magnesium

Question 4.1.3 The shape of a *single crystal* can usually be expressed as one of three types. What are these types? For each of the three types, give an example of a mineral which has this shape.

equi-dimensional, prismatic, tabular

Question 4.1.4 What is *lustre*? Name three different kinds of lustre and, for each type, give an example of a mineral which shows this lustre.

lustre is the sheen or gloss of a crystal

Question 4.1.5 What is *Mohs' scale*? How might this be used to help distinguish different minerals?

moh's scale is a hardness scale

Question 4.1.6 Diamond and graphite have the same chemical composition, but very different hardnesses. Why are their hardnesses different?

They have very different crystal structures. Diamonds are bonded strongly in all directions while graphite is weaker.

Question 4.1.7 Why is it that mica has perfect cleavage, but another silicate mineral, quartz, has no cleavage?

Because the bonding between different layers is weak

Question 4.1.8 What is the difference between a *cleavage plane* and a *crystal face*?

A cleavage plane is a plane of weakness. Crystal face is the external form of the crystal which has grown naturally.

Question 4.1.9 What important rock-forming mineral can easily be identified using the acid test? Why does quartz not react with acid?

calcite is a form of calcium carbonate and reacts to form CO₂. Quartz is a form of silicon dioxide and is not very reactive.

'Properties of minerals' is on the Block 10 DVD. You should start this activity now.

Activity 4.2 Minerals gallery



(The estimated time for this activity is 45 minutes.)

In this DVD-multimedia activity you will have the opportunity to look at ten common minerals. Some of these are important rock-forming minerals, which you will meet again later in this course. A knowledge of their properties will help you to identify these minerals in rock specimens.

You should aim to familiarize yourself with the distinctive features of each of the ten minerals. You should pay particular attention to which of them are silicate minerals and which are non-silicate minerals, and to which structural group each silicate mineral belongs. Also you should relate the observed properties to the underlying crystal structure, and note the reasons why some minerals have particular properties (e.g. well-defined cleavage).

You should use the information on the DVD to answer the questions below. You may wish to study the DVD material first and then use the questions to assess your understanding of the material. Alternatively you could take the questions in turn, and use them to guide your exploration of the DVD material.

Question 4.2.1 Use information from the 'Minerals gallery' to complete Table 4.2.1.

(You will need the information in this table for later sections in this block.)

Table 4.2.1 Main physical and chemical properties of some common rock- and ore-forming minerals.

Mineral	Classification	Composition	Colour	Lustre	Cleavage	Hardness
quartz (rock crystal)	silicate (framework structure)	SiO ₂	colourless — can be pink, mauve or smoky	glassy	none (irregular fracture)	7 (harder than steel)
feldspar	silicate (.....)	alkali, (K,Na)AlSi ₃ O ₈ plagioclase, from NaAlSi ₃ O ₈ to CaAl ₂ Si ₂ O ₈				6–6.5
mica	silicate (.....)	pale (muscovite) KAl ₃ Si ₃ O ₁₀ (OH) ₂ dark (biotite) K(Fe,Mg) ₃ AlSi ₃ O ₁₀ (OH) ₂				2.5
pyroxene	silicate (.....)	(Ca,Mg,Fe) ₂ Si ₂ O ₆				5.5–6
garnet	silicate (.....)	(Ca,Fe,Mg) ₃ (Al,Fe) ₂ Si ₃ O ₁₂				7
olivine (peridot)	silicate (.....)	(Mg,Fe) ₂ SiO ₄				6.5–7
calcite	non-silicate — carbonate	CaCO ₃				3
halite (rock salt)	non-silicate — halide	NaCl	colourless (but can be tinted)	glassy	three perfect, cleavages causing crystals to break into cubes	2
pyrite (fool's gold)	non-silicate — sulfide	FeS ₂	brassy-yellow	metallic	poor (brittle fracture)	6–6.5
haematite (bloodstone or kidney ore)	non-silicate — oxide	Fe ₂ O ₃	brown-black	metallic to earthy	poor (brittle fracture)	5–6

Question 4.2.2 Three unknown minerals have been found, and their properties are as follows:

- (a) Mineral A is colourless with glassy lustre and cubic cleavage, and it is soft.
- (b) Mineral B is yellow with a metallic lustre; it is hard, and sparks are produced when it is struck with a hammer.
- (c) Mineral C is translucent and white, with two good cleavages, and it is hard (but not quite as hard as steel).

Use your completed version of Table 4.2.1 to identify minerals A–C.

Question 4.2.3 Suggest how you might distinguish between the two minerals in each of the following pairs on the basis of *one* distinctive mineral property (colour, shape, lustre, cleavage, hardness or acid test): (a) quartz and feldspar; (b) mica and pyroxene; (c) pyrite and haematite; (d) halite and calcite.

Note that you are *not* expected to remember the precise details of the structures, chemical formulae and properties of the ten minerals in the gallery; Table 4.2.1 will provide a useful summary of the important information.

'Minerals gallery' is on the Block 10 DVD. You should start this activity now.

Activity 5.1 Revision: basalt and granite

Aims and introduction

You examined samples of basalt and granite in Activity 9.1 of Block 3. The aim of this activity is to refresh your memory about the important properties of these rocks, since an appreciation of these properties will help your understanding of Section 5.

Practical procedure

Task 1 Distinguishing rock types — rock textures

Examine the basalt (Specimen 5) and granite (Specimen 6) samples again. In particular, look closely at the texture of the samples using your hand lens. Also, try to prise out a few grains with a penknife blade or the point of a nail. How do you know these samples are *igneous* rocks?

Task 2 Distinguishing igneous rocks — colour and grain size

(a) Observe the overall appearance of the basalt and granite samples, and note particularly their colour and their grain size. Hold the samples side-by-side to get a clear comparison and make a note of the ways in which they differ.

(b) Which of your observations — of colour or of grain size — tells you about differences in the mineral composition of the rocks, and which tells you about the way that the rocks crystallized? Which sample is an extrusive rock, and which is an intrusive rock?

Keep Specimens 5 and 6 to hand for Activity 5.2.

Activity 5.2 Exploring the mineral content and composition of igneous rocks — basalt and granite revisited

(The estimated time for this activity is 15 minutes.)

Aims and introduction

In the 'Minerals gallery' DVD-multimedia activity (Activity 4.2), you met a variety of minerals, some of which are present in your samples of basalt and granite. In this activity you will identify the minerals normally found in these rocks, you will familiarize yourself with the chemical composition of these minerals, and you will see how they contribute to the overall chemical composition of each rock.

Practical procedure

Task 1

Look carefully at the granite sample (Specimen 6) using your hand lens, and try to distinguish the *three* minerals present. For each mineral describe its colour, its average grain size, its lustre, and its cleavage. Refer back to the 'Properties of minerals' DVD-multimedia activity (Activity 4.1) if you need to remind yourself of the meaning of these last two properties. Confirm that your observations accord with the properties of the minerals quartz, feldspar and mica, which are described in the 'Minerals gallery' DVD-multimedia activity (Activity 4.2) and which you should have summarized in Table 4.2.1.

Now look closely at the basalt sample (Specimen 5). It is more difficult to observe all of the minerals in the basalt. Try to recognize a few large, dark crystals of *pyroxene*, their outlines visible on cut surfaces and their cleavage planes reflecting from broken surfaces. Also, try to recognize the many long, narrow, grey (white near weathered surfaces) crystals of *plagioclase feldspar*, often broken along cleavages that glint in the light. Both of these minerals also make up much of the dark, fine-grained material, the so-called *groundmass*, in which the larger grains are set. (We could tell this if we observed a thin slice of the rock under a microscope.)

Task 2

(a) Write down the name of each mineral present in the *granite*, and its chemical formula, taken from Table 4.2.1. You may assume that most of the feldspar is alkali feldspar, although it would be necessary to look at the rock under a microscope to confirm just how much alkali feldspar and how much plagioclase feldspar are present. (Note that you



Equipment

KIT ITEMS

Specimens 5 and 6
hand lens

NON-KIT ITEMS

ruler (marked in millimetres)
penknife or large nail



Equipment

KIT ITEMS

Specimens 5 and 6
hand lens

NON-KIT ITEMS

ruler (marked in millimetres)

don't need to remember these particular formulae, but it is important to appreciate which elements occur in the main rock-forming minerals.)

Similarly, write down the name of each mineral in the *basalt*, together with its chemical formula. Assume that the plagioclase feldspar is at the calcium-rich end of the composition range.

(b) The chemical formulae for the minerals in each rock indicate the elements that are present. Use this information to estimate which elements (ignoring oxygen and hydrogen) are likely to be found in greater abundance in the granite than in the basalt, and vice versa. You should assume that the granite sample comprises 45% quartz, 45% alkali feldspar and 10% dark mica, and that the basalt sample comprises 50% plagioclase feldspar and 50% pyroxene.

Activity 5.3 Revision and consolidation

In the second half of the course you are frequently making use of science that was introduced earlier, and we often provide references to the places where this material was introduced. This gives you opportunities to revise this material, which will help reinforce it in your memory, and will have benefits when you are reviewing the course before moving on to higher level study.

(a) If you studied Block 9 then you may recall that in Activity 15.1b, at the end of Block 9, we asked you to review the methods that you had used for revision in that block, and to identify which methods you had found most helpful. Have a quick look at the notes and comments for that activity now.

(b) As you are studying the rest of Block 10, there will be frequent references to concepts that you met in earlier blocks, in particular to concepts in Block 3. In some places we have included activities that provide a framework for revision, but in most places we have just referred to the appropriate section number. Spend a minute thinking about what you will do when you meet these references.

(c) Also think about how you are going to produce notes, diagrams and summaries as you study the rest of this block that will be useful for developing revision techniques needed for higher level study.



Activity 6.1 A look at sedimentary materials in soil

(The estimated time for this activity is 30 minutes, spread out over a day.)

Equipment

KIT ITEMS

hand lens

NON-KIT ITEMS

tall clear-glass jar, preferably with a tight-fitting lid
soil

trowel or old spoon

water

spoon or fork

ruler (marked in millimetres)

paper and pencil

Aims and introduction

The aim of this activity is to investigate the different sedimentary materials in a sample of soil, and how a mixture of sedimentary materials settles in water. You will use soil in the experiment because soils usually contain a variety of common sedimentary materials.

Safety

Soil can contain harmful micro-organisms. You are strongly advised to cover any cuts and abrasions with plasters and to wear rubber gloves when collecting and handling the soil. As with any practical work, wash your hands when you have finished.

Task 1

First find your sample of soil, and break it down with a trowel or an old spoon. Remove any large stones (>10 mm), leaves, roots, worms and other organic debris. Fill the jar about one-third full with the soil, and add water until the jar is about three-quarters full. If the soil is very dry, it may need time (some hours) to soak and disaggregate. Tighten the lid and shake the jar vigorously for about a minute. Then let the jar stand, and observe what happens for a few minutes. Record your observations, noting down especially what sort of material you see settling in the jar and the condition of the water. If you think you may have missed anything, shake the jar again and repeat your observations. Then leave the jar to stand for several hours, or possibly overnight.

Task 2

After the jar has been standing for at least a couple of hours, make notes of what you can see in the jar. Describe any variations in the grain size, or in the colour of the material in the jar.

Task 3

Draw a sketch of the jar and its contents. Label each variation in the properties of the sediment. This is your permanent record of the experiment, so make it as informative as possible.

Task 4

Finally, use a spoon, or perhaps a fork handle, to remove some material from different layers of sediment in the jar, and put these samples on a saucer. Examine these samples closely with your hand lens, and make a note of the size, shape and colour of the different types of grain present.

Activity 6.2 Sedimentary grains, transport and sorting

(The estimated time for this activity is 50 minutes.)

In the first part of this activity you will study the DVD-video sequence 'A story in sand'. This investigates how sediment grains are formed by weathering; how they are transported by water and wind; and the types of sediment that result from these processes. The activity goes on to show what can be deduced about the origins of sediments and sedimentary rocks (including the sandstone sample from your Kit) from simple observations and measurements.

While you are studying the DVD-video, be prepared to note down your answers to the questions in Task 1.

Task 1

- What processes break down exposed rocks to produce sediment grains?
- What are the three ways in which grains move downstream in flowing water?
- How do typical river sediments differ from typical beach sediments?
- How do the shape and surface texture of wind-blown grains differ from water-lain grains?

'A story in sand' is on DVD 2 (DVD-video sequence 294–376). You should view this now.

Task 2

You should now draw a histogram (like that featured in the DVD-video) to describe the grain-size distribution of a sample of sand similar to that collected from the river shown in the video; the sieving data for this sediment are given in Table 6.2.1.

This requires you to calculate the percentage by mass of sediment retained in each sieve. To do this you should first calculate the total mass of sediment, and then you should express the mass in each sieve as a percentage of the total mass.

Use Figure 6.2.1 to plot a histogram for the grain-size distribution, using the mass percentages that you have calculated in Table 6.2.1. Each vertical bar on the histogram should have a height corresponding to the mass percentage in a particular sieve. Note that the sieve sizes have been marked on the horizontal axis in the conventional way for displaying grain-size distributions, with the *largest sieve size on the left*. Note also that the bar representing the per cent mass in a sieve should be drawn *to the left* of the sieve size; so for example, the bar for the 0.5 mm sieve should be drawn between 0.5 mm and 1 mm. This is because the 0.5 mm sieve will retain all grains with sizes between 0.5 mm and 1 mm (the size of the grains that just pass through the next largest sieve).

Would you describe the sediment for which you have plotted the histogram as being well-sorted or poorly-sorted?



Equipment (for Task 4)

KIT ITEMS

Specimen 2
hand lens

NON-KIT ITEMS

graph paper, preferably with
millimetre squares
penknife or large nail

Table 6.2.1 Grain-size data from a sieving experiment with a sand sample.

Sieve size/mm	Mass in sieve/g	% of total mass
4	1.0	
2	1.4	
1	4.8	
0.5	7.1	
0.25	14.5	
0.12	9.4	
0.06	7.3	
pan	2.2	
total		

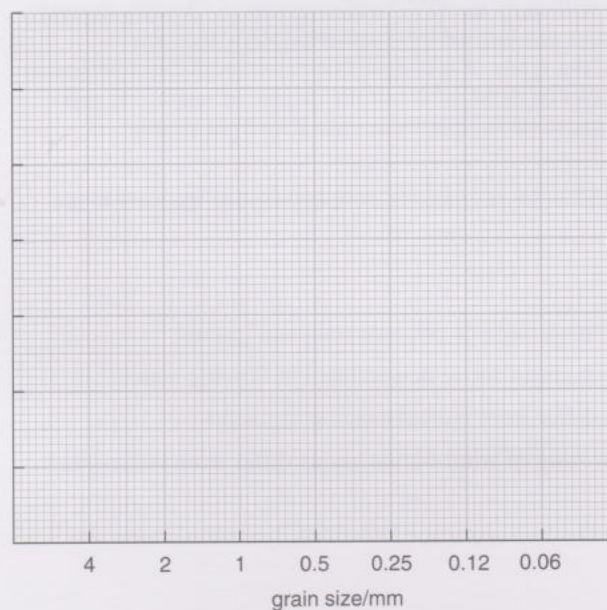


Figure 6.2.1 Graph paper for plotting a histogram showing the sediment grain-size distribution for the sieving experiment data in Table 6.2.1.

Task 3

Histograms are a very visual way of representing the grain-size distribution of a sediment. Certain types of distributions are characteristic of sediments deposited in particular environments, and in the DVD-video sequence you saw histograms of desert sand and beach sand.

(a) Recalling observations made in the DVD-video, suggest which of the histograms shown in Figure 6.2.2a correspond to the grain-size distributions for river, beach and desert dune sands, and explain why.

(b) Cumulative frequency distribution diagrams, which featured in the DVD-video, are an alternative to histograms for representing sediment grain-size data. Which cumulative frequency distribution diagrams in Figure 6.2.2b match with which histograms in Figure 6.2.2a?

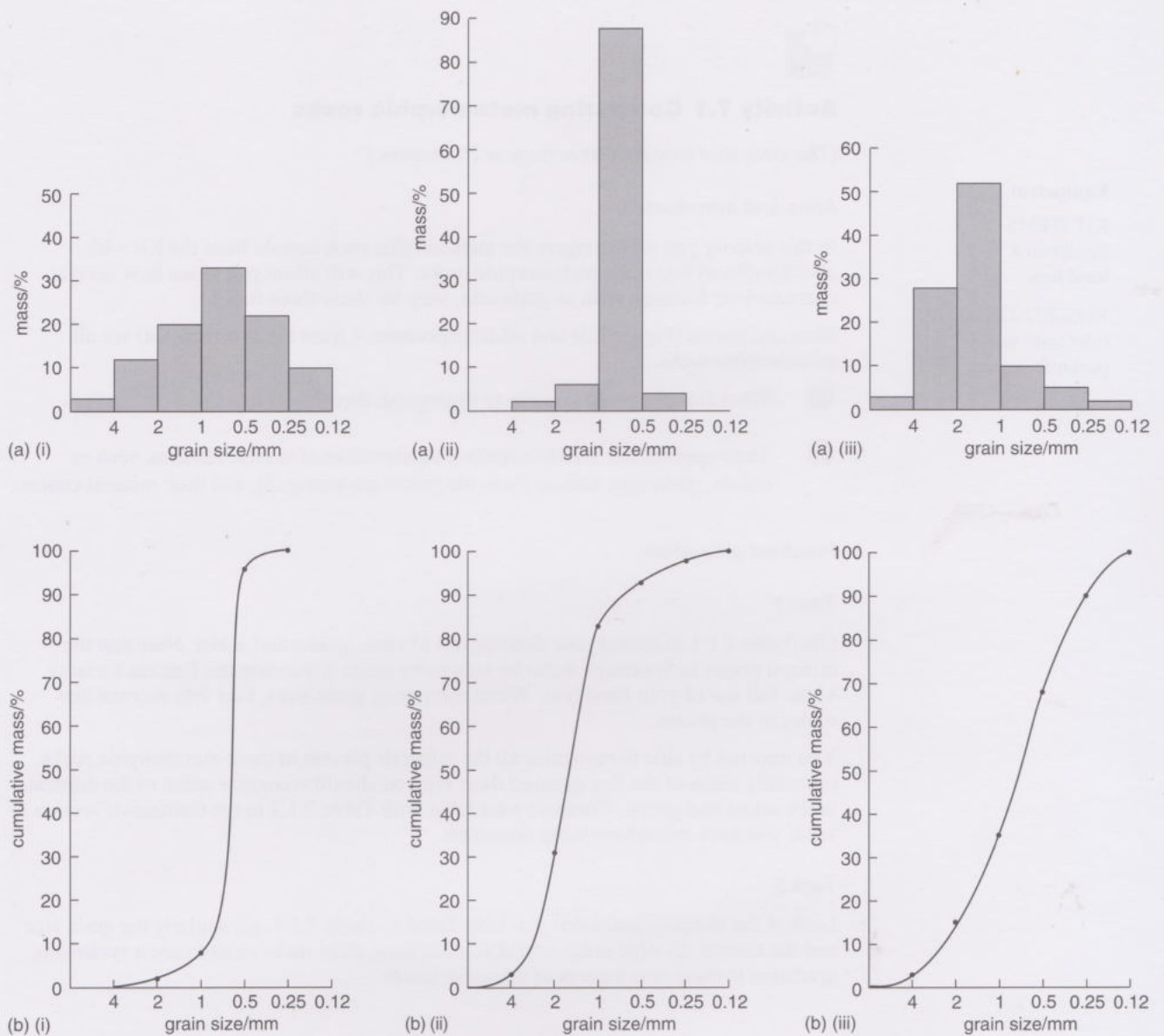


Figure 6.2.2 (a) Grain-size histograms corresponding to three sedimentary environments. (b) Cumulative frequency distribution diagrams, featuring equivalent sediment grain-size distributions to those in (a).

Task 4

In the DVD-video sequence, you saw sand grains from a beach and from a desert. Now you can look at some grains of sediment present in a real rock. Take the sandstone sample (Specimen 2) and scrape off some grains. Try first with a fingernail, and then with the point of a steel nail or a penknife blade. Is it easier or more difficult to remove grains from the sandstone than it was to remove them from the igneous samples in Activity 5.1? Why do you think that is? Prise off about 20 to 30 of the grains onto a piece of millimetre-squared graph paper, and use your hand lens to examine them. What kinds of grain can you see, and roughly what range of grain sizes are present? Make a note of this information for use in Section 6.2.3. Also, look at the rock with your hand lens, and describe the shape and the arrangement of the grains. What medium would have transported them? Place a few drops of water on the surface of the rock. What happens to it and what does that tell you? Again, make a note of this information for use in Section 6.4.



Activity 7.1 Comparing metamorphic rocks

(The estimated time for this activity is 20 minutes.)

Equipment

KIT ITEMS

Specimen 4
hand lens

NON-KIT ITEMS

ruler (mm scale)
penknife or large nail

Aims and introduction

In this activity you will compare the metamorphic rock sample from the Kit with photographs of two other metamorphic rocks. This will allow you to see how several characteristic features, such as grain size, vary for these three rocks.

Slate and gneiss (Figure 7.3) and schist (Specimen 4 from the Practical Kit) are all metamorphic rocks.

- What features could you use to distinguish them?
- Their appearance, which is really a combination of several features, such as colour, grain size, texture (how the grains are arranged), and their mineral content.

Practical procedure

Task 1

Use Table 7.1.1 to record your descriptions of slate, gneiss and schist. Note that the mineral grains in Specimen 4 can be seen more easily if you wet the flat, cut surfaces. Make full use of your hand lens. When comparing grain sizes, take into account the scales of the photos.

You may not be able to recognize all the minerals present in these metamorphic rocks, especially those of the fine-grained slate, but you should recognize some of the minerals in the schist and gneiss. Compare your table with Table 7.1.2 in the Comments section to see if you have missed anything important.

Task 2

Look at the characteristics that you have listed in Table 7.1.1, particularly the grain size and the texture. In what order would you put these three rocks so as to see a systematic gradation in these two aspects of their character?

Table 7.1.1 Comparison of properties of slate, gneiss and schist.

Property	Slate	Gneiss	Schist
grain size			
colour			
texture			
minerals			

Activity 7.2 Processes of the rock cycle

By now, you should appreciate that any type of rock, whether it be igneous, sedimentary or metamorphic, can undergo a variety of geological processes that can convert it into other types of rock. The aim of this activity is to consolidate your understanding of some of the main processes involved.

Task 1

Figure 7.2.1 is a schematic diagram of the rock cycle.

(a) Label the five ellipses on Figure 7.2.1 with the processes from the list below that are likely to occur there (you will need to use one of the labels twice):

- weathering and erosion
- deposition of sediments
- partial melting
- recrystallization

(b) Label the four boxes in particular settings on Figure 7.2.1 with the rock types most likely to be formed there:

- intrusive igneous rock
- extrusive igneous rock
- metamorphic rock
- sedimentary rock

(c) Rock-forming processes involve some movement of the material from which a new rock is made. Movement is brought about by *burial*, *uplift*, agents of *transportation* at the Earth's surface (i.e. wind, water, ice), and *eruption of magma*. By labelling arrows, show on Figure 7.2.1 where these movements occur in the rock cycle.

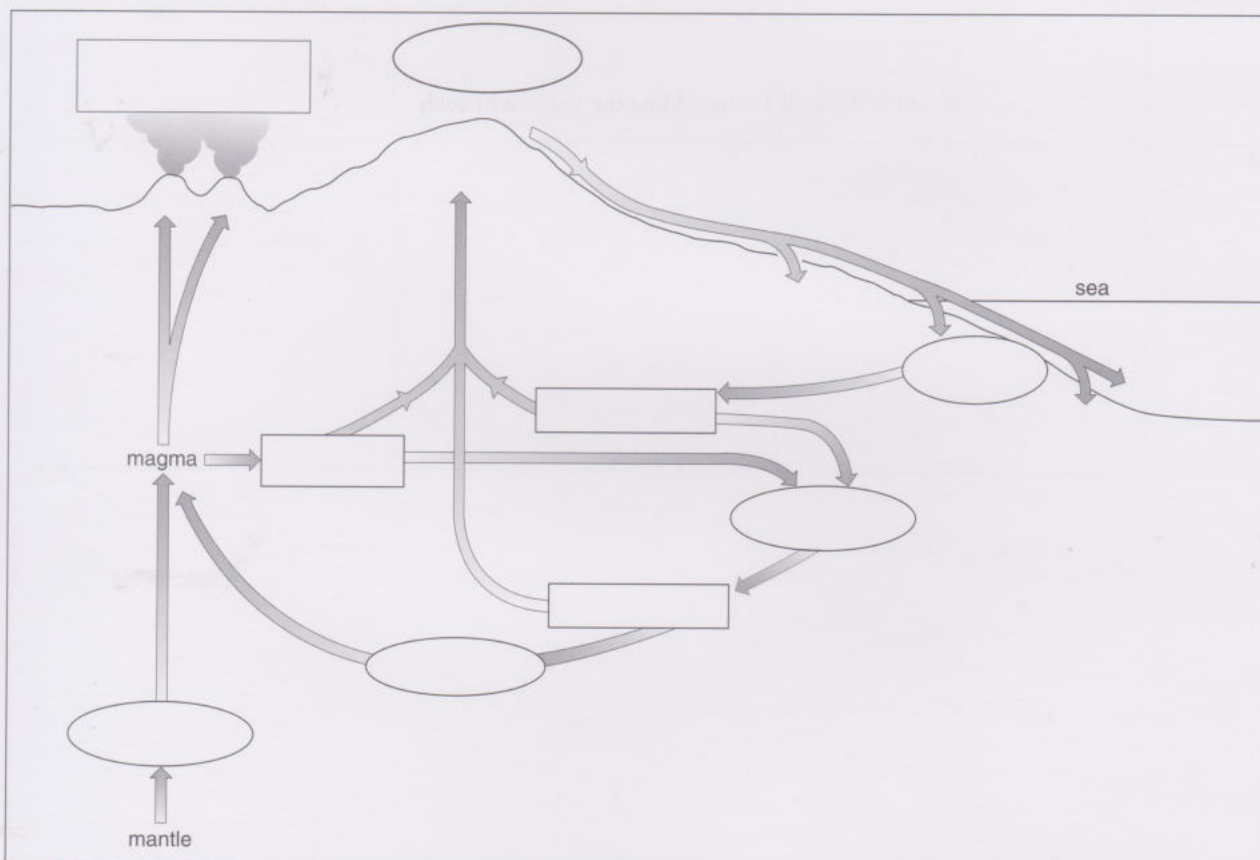


Figure 7.2.1 A schematic diagram of the rock cycle.

Task 2

Label Figure 7.2.1 with the numbers 1–6 to show where the following processes occur within the rock cycle:

- 1 A shale gets heated and recrystallizes to form a gneiss.
- 2 A gneiss partially melts to form a granitic magma.
- 3 A granite weathers to form grains of quartz feldspar and mica.
- 4 Grains of feldspar and mica weather to form clay minerals.
- 5 Clay minerals and silt accumulate to form shale.
- 6 Felsic magma cools slowly to form a granite pluton.

Activity 8.1 Calculating an average growth rate for Etna

(The estimated time for this activity is 15 minutes.)

The purpose of this activity is to calculate the *average* rate at which Etna has grown between 1758 and 1951 by using the dates of historical lava flows and their volumes. The activity will also give you some practice with graphical analysis of data.

In order to calculate the average rate at which the volume of Etna has increased, you will plot a graph of the cumulative volume of the recorded lava flows. The cumulative volume of the erupted lava is simply the sum of the volumes of all lava flows since an arbitrary starting date. The volumes of all the lava flows from 1766 to 1951 are listed in Table 8.1.1. For the starting year we have used 1758, the year of the eruption prior to the 1766 eruption. The volume of the 1766 lava flow was $106 \times 10^6 \text{ m}^3$, and so at the end of 1766 the cumulative volume since 1758 was $106 \times 10^6 \text{ m}^3$. (Note that this volume would cover a $10 \text{ km} \times 10 \text{ km}$ square to a depth of just over 1 m.) The next eruption in 1780 added a further $15 \times 10^6 \text{ m}^3$. Adding this to the $106 \times 10^6 \text{ m}^3$ of the 1766 lava flow gives a cumulative volume of $121 \times 10^6 \text{ m}^3$ at the end of 1780. And so on.

Task 1

Complete the cumulative volume column in Table 8.1.1 by adding the volume of each lava flow to the total of the previous lava flows.

Task 2

Now display this information in the form of a graph, using the blank grid in Figure 8.1.1. Plot a graph of the cumulative volume against the year of eruption. Label the axes clearly, and choose the scales to use as much of the grid as you require to illustrate the information clearly. Then draw a best-fit straight line through the data, and calculate the gradient of this line. What does the gradient of this line represent?

Table 8.1.1 Volumes of lava flows from eruptions of Etna, 1766–1951.

Year of eruption	Volume of lava flow / 10^6 m^3	Cumulative volume / 10^6 m^3
1766	106	106
1780	15	121
1793	80	
1809	19	
1812	25	
1819	31	
1832	50	
1843	50	
1853	128	
1865	46	
1879	36	
1886	56	
1892	100	
1908	3	
1910	34	
1911	36	
1923	45	
1928	30	
1942	2	
1947	4	
1949	3	
1951	50	

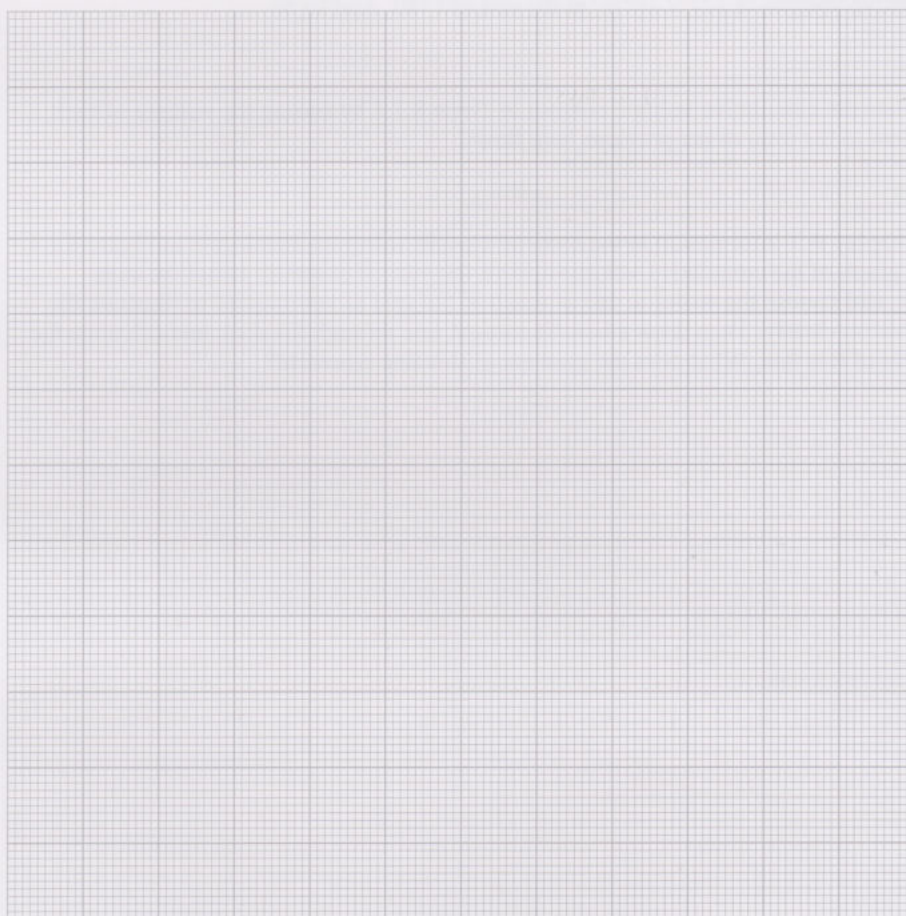


Figure 8.1.1 A grid for use with Task 2.

Activity 8.2 Revision: radioactivity

This activity will revise aspects of radioactivity that you met in Block 7 that are important for understanding the technique of radiometric dating. You may recall that we recommended very strongly that you should not omit study of the first part of Block 7.

- (a) What do the terms *parent* and *daughter* mean in the context of radioactive decay?
- (b) A particular isotope of uranium is represented by the symbol ${}^{235}_{92}\text{U}$. What do the two numbers mean?
- (c) The five different types of radioactive decay that you met in Block 7 are listed in the first column of Table 8.2.1. Complete this table by filling in the blank cells.

Table 8.2.1 The different types of radioactive decay process.

Decay process	What is emitted?	How does the nucleus change?
alpha		A decreases by 4, Z decreases by 2
beta-minus		
beta-plus	positron and electron neutrino	A is unchanged, Z decreases by 1
electron capture	electron captured and electron neutrino emitted	A is unchanged, Z decreases by 1
gamma		

- (d) The term *half-life* was introduced in the DVD-multimedia activity, 'Nucleons in nuclei' (Activity 5.1 in Block 7). What is meant by the half-life of a radioactive isotope?
- (e) If a radioactive isotope has a half-life of 3 days and there were initially 1000 atoms of this isotope present in a sample, how many atoms of this isotope would be present after (i) 3 days, (ii) 9 days, and (iii) 36 days?
- (f) Can the half-life of a radioactive isotope be changed?

Activity 8.3 Calculating the value of D/P for a simple radioactive decay scheme

(The estimated time for this activity is 15 minutes.)

In this activity you will calculate the numbers of atoms of parent and daughter isotopes present in a sample after various numbers of half-lives, and will use these results to calculate the value of D/P at these times. You will then compare these D/P values with those calculated from Equation 8.3, derived in the book, and will plot a graph that shows how the value of D/P depends on the number of half-lives that have elapsed.

Task 1

Consider a sample that initially has 1 024 radioactive parent atoms — a ridiculously small number, but one that lends itself to easy manipulation. Calculate the number, P , of parent atoms left after successive half-lives, and the number, D , of daughter atoms that have been produced, and enter these numbers in Table 8.3.1. Remember, after each successive half-life, the number of parent atoms remaining is half the number at the beginning of that half-life period. Then calculate the value of D/P at each time, and enter these values in the table.

The expression for D/P that was derived in the book is

$$D/P = 2^n - 1 \quad (8.3)$$

Use this expression to calculate the value of D/P for various values of n , and check that the values calculated from the equation are the same as those in the table.

Table 8.3.1 Numbers of atoms of parent and daughter atoms during radioactive decay.

Number of half-lives elapsed, n	Number of parent atoms, P	Number of daughter atoms, D	D/P
0	1 024	0	0
1	512	512	1
2			
3			
4			
5			
6			
7			
8			
9			
10			

Task 2

- Use the graph paper in Figure 8.3.1 to plot a graph of the number of parent atoms P (on the vertical axis) against the number of half-lives n (on the horizontal axis).
- Then plot the value of D/P against the number of half-lives n on the graph paper in Figure 8.3.2.
- Describe in words what these graphs are showing.

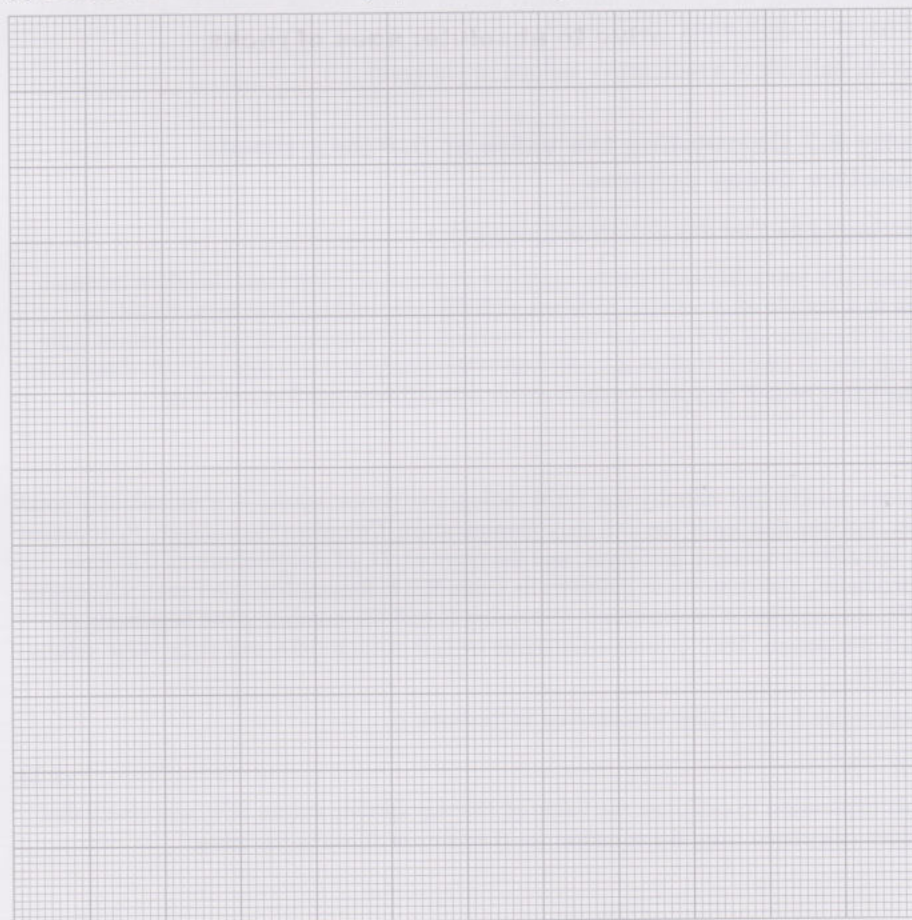


Figure 8.3.1 A grid for use with Task 2a.

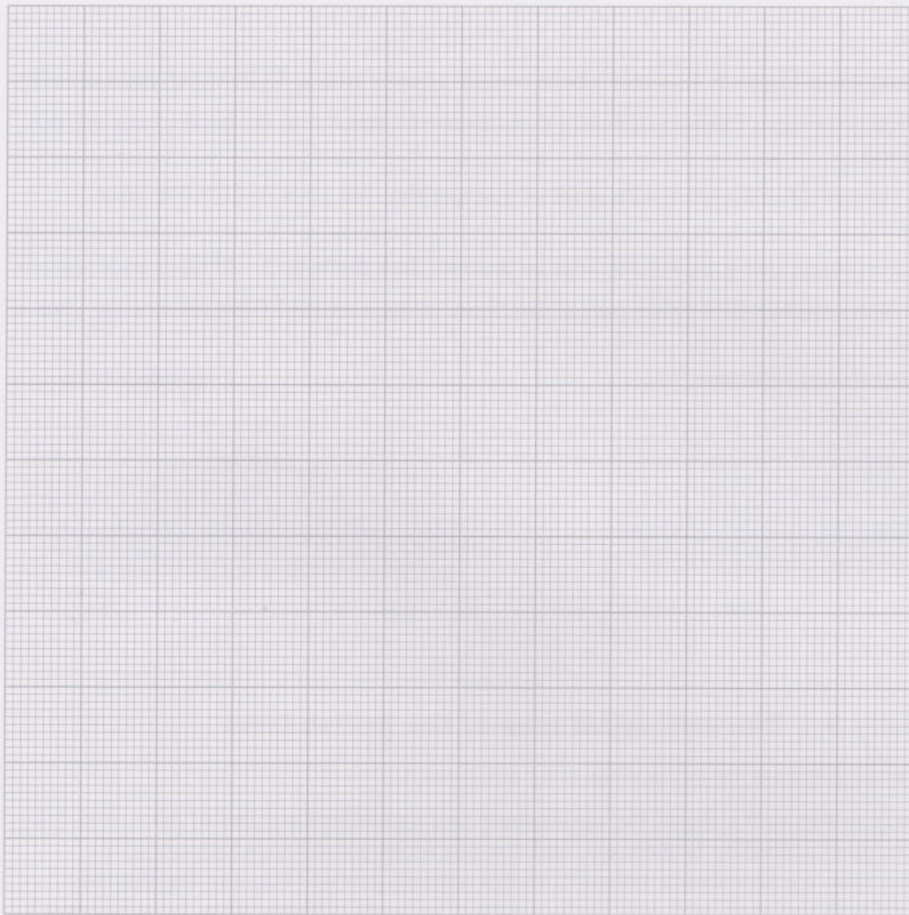


Figure 8.3.2 A grid for use with Task 2b.

Activity 8.4 From relative to absolute: ages of rocks

This activity gives you some practice at deducing relative and absolute ages of rocks, using the principles discussed in the book.

Task 1

In Figure 8.4.1, there are two series of sedimentary rocks, A–E and F–I, and two igneous bodies, a dyke (J) and a sill (K). Study the relationships between these different rock formations and answer the following questions.

- Which series of rocks is older, series A–E or series F–I?
- Is igneous rock J or K the older, and why?
- Arrange the rocks in four age groups, starting with the oldest.
- What is the name given to the surface at the base of rock F?
- If rock K were a lava flow, how would that affect your answer to (c)?

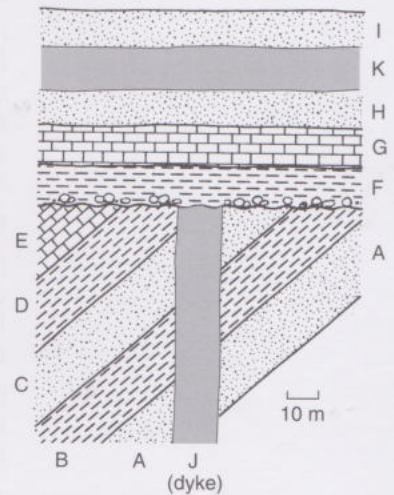


Figure 8.4.1 Two series of sedimentary rocks.

Task 2

The granites in Figure 8.4.2a and b both contain zircons with a $^{207}\text{Pb}/^{235}\text{U}$ ratio of 0.70.

- What is the age of these granites? (You can use Figure 8.6 in the book to answer this question.)
- Is the granite in Figure 8.4.2a older or younger than the beds A–D? Give your reasons.
- Is the granite in Figure 8.4.2b older or younger than the beds X–Z? Give your reasons.
- Will the sediments in either part of the figure contain fossils? Give reasons for your answer.

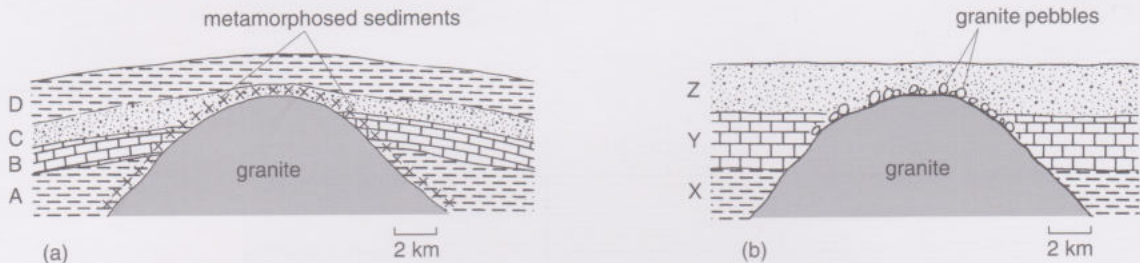


Figure 8.4.2

Activity 9.1 The geological map of the British Isles

(The estimated time for this activity is 15 minutes.)

The map in Figure 9.1 shows the sedimentary and metamorphic rocks of the British Isles, colour-coded according to their age, and igneous rocks colour-coded according to whether they are intrusive or volcanic. In this activity you will begin to familiarize yourself with this map, and with the locations of rocks of different ages, by answering a series of questions. You may find your hand lens useful for examining some of the map's details more closely.

- Find out the approximate age and the type of rock in the area where you live. If you do not live in the British Isles, identify the age and type of rock in Cardiff.
- Describe how the rock ages and rock types change as you travel southeastwards along a line between Nottingham and London.
- Identify the colours in the key representing rocks of the first three periods of the Palaeozoic (i.e. Cambrian, Ordovician and Silurian), and then locate these rocks on the map and list the main areas where they occur. Describe briefly any distinct patterns in the distribution and trend of these rocks. Note that the word 'trend' is used to denote the general direction in which geological features such as beds, folds and faults run across the country when seen in plan view, such as on this map.
- Where are the oldest rocks in the British Isles located?
- Study the rocks along an approximate line on the map between the far northwestern coast of Scotland (such as the northern tip of the large Isle of Lewis in the Outer Hebrides) and Edinburgh. How old are the various rocks along this line and what rock type are they? Are there any major time-breaks across adjacent rock types along this line?
- Locate the areas outside Scotland, northern Ireland and mid-Wales where there are Devonian rocks. Is there anything different about the trend of these rocks compared with the trend of the Devonian rocks further north?

As you read through the rest of Section 9, you may wish to check the location of places mentioned by referring to Figure 9.1.1.



Figure 9.1.1 Map showing the locations of many of the places mentioned in Section 9.

Activity 9.2 A geological field trip

(The estimated time for this activity is one hour.)

This DVD-multimedia activity involves three field visits to Permian and Triassic rocks exposed in southwest Britain, and introduces some basic geological field techniques. It will show you how to make observations in field situations, and how to describe and record your observations, both in the form of notes and as a geological sketch.

We recommend that you visit the sites in the correct age sequence, so you should start your trip at Dawlish, then go on to Budleigh Salterton, and finally visit Aust Cliff. At each locality you will be asked to make notes of what you see. You should record your observations in the 'notebook pages' below; the headings provided in these pages give you an indication of what you should be looking for. When you have completed your visit to a locality, sample pages from a notebook will be displayed on the screen. You should not be concerned if you miss some of the details — it takes time to understand which features are important and to be able to recognize them in a new situation, and you will probably find that you see more on a second visit. However, you should add to your notebook pages below any details that you missed, so that you have a complete summary of each location.

Note that we have provided text transcripts of the audio commentaries with this activity; the first two lines of these appear in a panel at the bottom of the screen. Positioning the pointer over the text panel and holding down the left mouse button will reveal the full text. We have also provided additional navigation buttons, labelled I, II, III, that allow you to move easily between a wide panoramic view of the location (I), a closer panoramic view (II), and a close-up view of a hand specimen of a rock from the location (III).

'A geological field trip' is on the Block 10 DVD. You should start this activity now. Use the following 'notebook pages' to record your observations.



Locality: Dawlish, Devon Rock age: Permian (270 Ma) <u>Rock characteristics</u> Colour: Red Texture: <i>grainy fragmentary</i> Grain shape: <i>rounded</i> Grain size: <i>1mm</i> Grain composition: <i>feldspar, quartz, mica</i> <u>Features</u> <i>layered cross-beds</i> <i>well defined beds about 1m thick</i> <i>clear cross-bedding</i> <u>Rock identification</u> Sandstone	<u>Description</u>
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Locality: Budleigh Salterton, Devon Rock age: Triassic (240 Ma) <u>Rock characteristics</u> Colour: Brown Texture: Grain shape: Grain size: Sorting: <u>Features</u> <u>Rock identification</u>	<u>Description</u>
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Locality: Aust Cliff Rock age: Triassic (220 Ma) Upper part of cliff <u>Rock characteristics</u> Colour: Texture: Grain size: Grain composition: Sorting: <u>Features</u> <u>Rock identification</u>	<u>Description</u>
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Figure 9.2.1 (a) A view of the cliff face at Dawlish.

Task 1 Producing a geological sketch from a photograph

After studying the 'Aust sketches' section of the activity, you should practice sketching a cliff face for yourself. Figure 9.2.1a is a photograph of part of the cliff at Dawlish. In this case, you already know about the rocks present at this general locality, so it should be relatively easy to identify the rocks in this cliff and recall some more detailed aspects of them. Produce a sketch that shows the main features of this cliff exposure. You will probably find it useful to follow the five steps outlined in the DVD-multimedia activity:

1 *Look carefully at the exposure.*

2 *Draw in skyline and ground.*

3 *Sketch in the main features in pencil using simple lines whenever possible.* If necessary, rub out and redraw particular areas until you're happy with them. Part of the skill of making successful geological observations at complex exposures is to follow any key feature (be it a bed, a fault, or whatever), as far as you can with your eye until it disappears from view. Similarly, the skill of making an effective geological sketch is to draw such a feature as a discrete, continuous line (where the feature is continuous), rather than to sketch a vague series of unconnected lines.

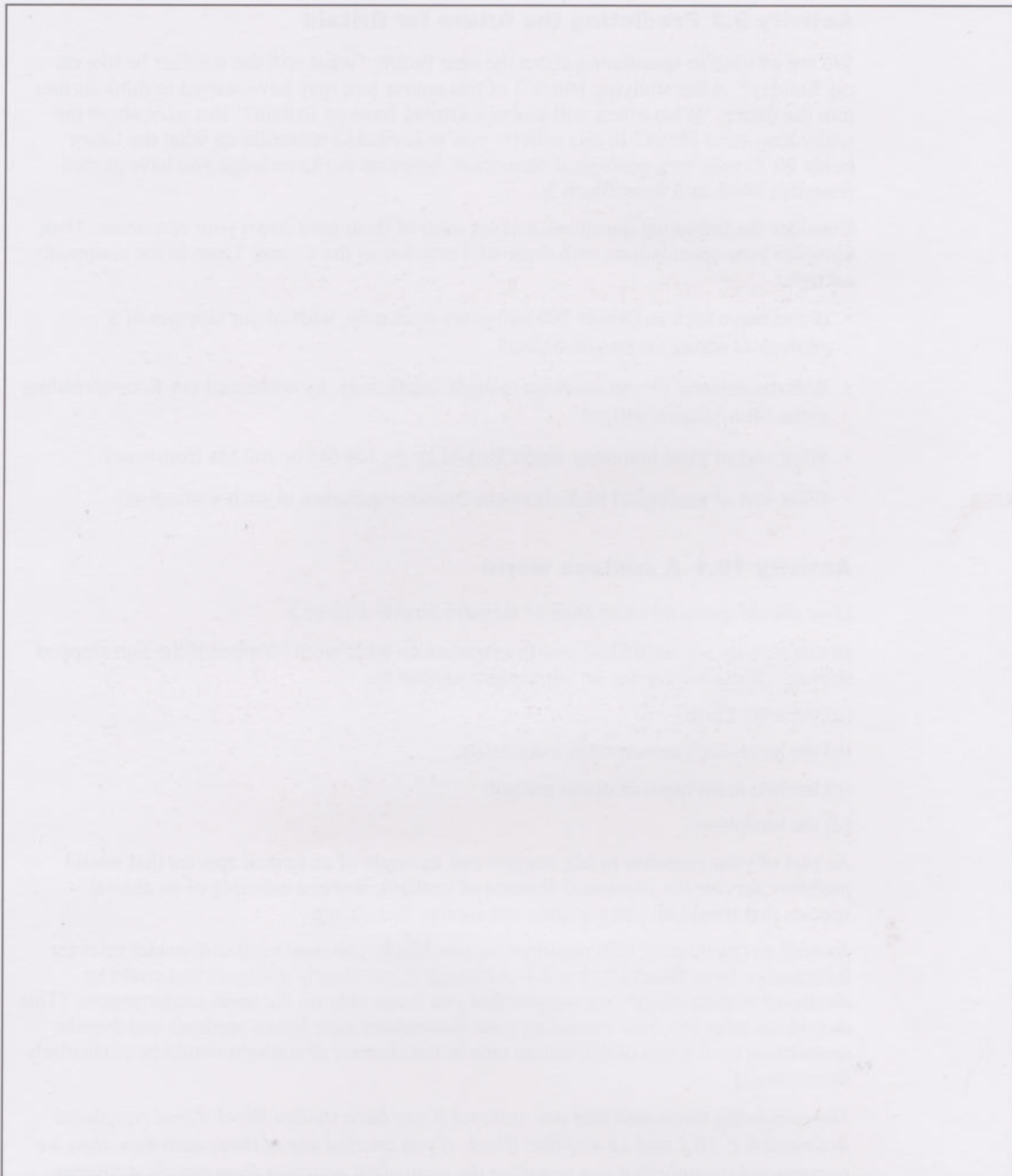


Figure 9.2.1 (b) Space for a sketch of the cliff face shown in the photograph in Figure 9.2.1a.

It is the in-situ bedrock details, especially the geological boundaries, that are important; ignore shadows from sunlight and features such as loose boulders, rabbit burrows, fallen branches, etc. (unless the feature is there to indicate precisely where the sketch was drawn). You can indicate the presence of patches of vegetation using your own simple symbols for grass, trees, etc. Do *not* try to emulate the fancy shading or ornament for different rocks that was shown in the second sample sketch on the DVD.

4 *Label the main features.*

5 *Add a scale.* You could make use of the fence, which is probably about 1 m high, shown at the top of the cliff.

6 *Add the approximate orientation:* SW is on the left and NE is on the right.

Activity 9.3 Predicting the future for Britain

We are all used to speculating about the near future: 'What will the weather be like on my holiday?' After studying Block 2 of this course you may have started to think further into the future: 'What effect will global warming have on Britain?' But what about the really long-term future? In this activity you're invited to speculate on what the future holds for Britain on a geological time-scale, based on the knowledge you have gained from this block and from Block 3.

Consider the following questions, and for each of them note down your responses. Then compare your speculations with those of a member of the Course Team in the comments section.

- If you came back to Britain 100 000 years from now, what major changes of a geological nature might you notice?
- Will the Atlantic Ocean continue to open indefinitely, by continued sea-floor spreading at the Mid-Atlantic Ridge?
- What sort of plate boundary might Britain be on 100 Ma or 200 Ma from now?
- What sort of geological hazards might Britain experience in such a situation?

Activity 10.1 A sunless world

(You should spend no more than 15 minutes on this activity.)

In this activity we would like you to speculate on what would happen if the Sun stopped shining. Write brief notes on what might happen to:

- (a) the solid Earth;
- (b) the large-scale atmospheric circulation;
- (c) the two main types of ocean current;
- (d) the biosphere.

As part of your response to (d), suggest one example of an animal species that would probably survive the continued absence of sunlight, and one example of an animal species that would almost certainly not survive this change.

As well as considering information from this block, you may need to consider relevant information from Blocks 2, 3 and 4. Although this is clearly a subject that could be discussed at great length, we suggest that you focus only on the main consequences. (This should not stop you from extending your discussions with fellow students and friends; speculating on the fate of the human race in the absence of sunlight would be particularly fascinating!)

The remaining three activities are optional if you have studied Block 9 and completed Activities 8.1, 10.1 and 13.4 of that Block. If you omitted any of those activities, then we recommend strongly that you complete the equivalent activities from among Activities 10.2, 10.3 and 10.4 below. If you have time, you may wish to complete some or all of these three activities even though you completed the equivalent activities from Block 9: this would help to reinforce your writing skills.

Activity 10.2 Interpreting rock textures and grain size: criticizing an answer to an assignment question

(This activity develops some of the same skills as those developed in Activity 8.1 in the Block 9 Study File. The estimated study time for the activity is about 30 minutes. It can be attempted after you have completed Section 7 of Block 10.)

This activity will help you to pull together what you have learned about rock textures and grain size in Sections 5–7. You will also improve your TMA writing skills by making a critical assessment of a piece of written work.

Imagine that you are a tutor, and you are to mark a piece of work from a student who has just finished reading Section 7 of Block 10. Beyond making a few notes as an *aide mémoire*, you are not required to do any writing yourself.

- (a) First of all, read the question that the student was asked to answer:

Explain what the textures and grain sizes of rocks can tell you about the processes by which rocks form and the conditions under which they form. Your explanation *should not exceed 330 words* and should include references to named rock types and also references to appropriate figures from Block 10, to illustrate your answer. The word limit does not include figure references. You should also show a good understanding of the following terms: crystalline texture; random orientation; mineral alignment; fragmental texture; cement; energy of environment; metamorphic grade.

- (b) Now look at the student's answer, below, and mark it against the mark scheme provided, paying attention to both the scientific content and the student's writing skills. To do this you will need to identify errors/omissions, judge the suitability of the rock types named and the figures cited, and judge the quality of the writing. The best order in which to approach the task is as follows.

- (i) Read the student's answer.
 - (ii) Make yourself familiar with the mark scheme.
 - (iii) Re-read the student's answer, awarding marks as you do so and making notes of any weaknesses that you detect.
- (c) When you have marked the answer, turn to the comments on this activity and compare your marks and notes with those of a tutor who marked the answer.

Student's answer

The texture of a rock is the way in which the grains are related to each other. In crystalline texture the crystals have grown into each other and this indicates that they have crystalized from a molten magma. If the crystals have all grown in different directions, i.e. they are randomly orientated, this means that they were able to grow unimpeded at first, another sign that they crystalized from a molten magma. If platy minerals in the rock are lined up parallel to each other, i.e. the rock shows crystal alignment (Figure 5.1(b)), this means the minerals grew under pressure (Figure 7.4) and the rock is metamorphic. If the grains in the rock only touch each other, so that there are spaces in between (Figure 5.1(c)), though the spaces may contain cement that holds the grains together, the rock has a fragmental texture which means it is sedimentary in origin, made up of an accumulation of rock or mineral fragments as separate grains. Sedimentary rocks usually show layering as well. Rocks that have a rough texture are usually course grained and rocks with a smooth texture are fine grained.

The grain size of an igneous rock shows how quickly it cooled. A course grained rock like granite cooled slowly, probably deep underground. Fine grained basalt rapidly, possibly as a larva flow at the surface. The grain size of a sedimentary rock tells us about the energy of the environment in which it was deposited (Figure 6.5). The faster water flows down hill the more gravitational energy it has. Course grains are only deposited from fast flowing water and so indicate a high energy environment. Fine grained sands are not deposited unless water flow is slow and so indicate a low energy environment. The grain size of a metamorphic rock shows the grade at which metamorphism occurred, i.e. the depth and temperature. A course grained gneiss shows high grade metamorphism at 550–700 °C and 20–35 km depth where it cooled slowly. A fine grained slate shows low grade metamorphism at 200–350 °C and only 5–10 km depth where it cooled more quickly. (347 words, excluding figure references)

Mark scheme

Science content

Definition of crystalline texture	1 mark
Crystalline texture typical of igneous and metamorphic rocks	2 marks
Explanation of random orientation of crystals in igneous rocks	2 marks
Explanation of mineral alignment in metamorphic rocks	2 marks
Definition of fragmental texture and cement	2 marks
Fragmental texture indicative of sedimentary rocks	1 mark

Grain size in igneous rocks related to rate of cooling	3 marks
Grain size of metamorphic rocks related to metamorphic grade	3 marks
Grain size in sedimentary rocks related to energy of depositional environment	3 marks

Named rock types	3 marks
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Citing of figures	3 marks
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Writing skills

Clarity of writing (no ambiguities, correct spelling and sentence construction)	2 marks
Conciseness (keeping to word limit, lack of irrelevant points and no over-long sentences)	2 marks
Coherence (account divided into paragraphs and written with a logical flow)	1 mark

Total marks	30 marks
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Now read the comments on this activity.

Activity 10.3 Improving your TMA writing skills and integrating sources from more than one part of the course

(This activity develops some of the same skills as those developed in Activities 10.1 and 13.4 in the Block 9 Study File. The estimated study time for the activity is 45 minutes. It can be attempted after you have completed Section 8 of Block 10.)

The aim of this activity is to help you to improve your TMA writing skills by presenting your answer to a question in the way that the question requires and by being critical of your own work. In addition, the activity requires you to integrate information from more than one block of the course (Section 11 of Block 3, and Sections 2 and 3 of Block 10). At the same time, you will be revising part of Block 3.

There are two parts to this activity. For the first part you will be writing an answer to a question of the type that you have met in TMAs. In the second part you will mark your answer using marking guidance similar to that used by your tutor.

(a) (30 marks) In no more than 300 words, explain how fossils can be used to provide evidence of continental drift and also to establish a biostratigraphic column. You should include an explanation of why the fossil fern *Glossopteris* and fossil ammonites might be suitable for one of these purposes, but are unlikely to be suitable for both purposes.

You should make sure that you pay attention to your writing skills (i.e. the *clarity*, *conciseness* and *coherence* of your explanation) as well as the science content of your answer.

(b) Now mark your answer, using the mark scheme on p.40 for guidance.

Activity 10.4 The Devonian to Cretaceous sedimentary history of Britain: making links

(This activity develops some of the same skills as those developed in Activity 13.4 in the Block 9 Study File. The estimated study time for the activity is at least 1½ hours. It can be attempted after you have completed Section 9 of Block 10.)

This activity requires you to plan and write an account of not more than 800 words in which you make links between various themes associated with the sedimentary history of

the Devonian to Cretaceous Periods in Britain. It is based predominantly on Section 9 of Block 10, and is designed to improve your skills at answering assignment questions. It is also good practice for the forthcoming end-of-course assessment. Your account will need to be rather more sophisticated than some of those you have written in the past; for example, simply presenting the relevant information in the order in which it is presented in Block 10 is not appropriate. You will also need to be very selective about which material you include.

We are aware that writing the account in full will be time-consuming, so we suggest (below) a long and a short version of the activity. Because of time constraints, we suggest that you refer to any figures you might think relevant from Block 10 by their numbers, rather than drawing them.

We want you to write an account of *not more than 800 words* in which you discuss the following assertion.

The changes in the sediments and sedimentary rocks that were deposited in Britain from the Devonian through to the end of the Cretaceous were influenced as much by plate tectonic activity and plate movement, as they were by changes in the climatic conditions and the environments in which they were transported and deposited.

We suggest that you tackle the activity as follows.

(a) Start by identifying the four key themes that your account will need to address, and then think about how to integrate them in a way that best answers the question.

(b) Remember that the question asks you to *discuss* the assertion. A discussion may involve different views or opinions and so this gives you the flexibility to amend the assertion, or even to disagree with it, if you feel the evidence merits this.

(c) A long scientific account will benefit from planning. To help you with this we recommend that you read *SGSG* Chapter 9, Sections 5.3 and 5.4 and then draw up your plan.

- Make brief notes of what you will include in your *introduction*.
- Select the points you will include in the *main body* of the account (including supporting figures), and put them in the order in which you will present them. Don't forget to reference any information from sources outside of Section 9.
- Plan what you will include in your *conclusion*.

(d) Having completed your plan you are ready to write your account, and here we suggest two options.

If you need to practise your writing skills and have the time available: write the complete account, including the introduction, main body and conclusion.

If you are short of time: write the introduction to your account in full, write a sentence about what is to go in each paragraph in the main body of the account, indicating the diagrams that you would include and where these might be positioned in the account. Then write your conclusion in full.

After completing either version of part (d), compare your account with an example of a full account in the comments on this activity.—

Mark scheme for Activity 10.3(a)

Science content

Fossils as evidence of continental drift [5 marks]

Land-dwelling and/or shallow water organisms

of the same type (or species) (1) and age (1)

found on different continents

show that the continents were once joined

[Block 3, Section 11.2]

1 mark

2 marks

1 mark

1 mark

Fossils used to establish the biostratigraphic column [7 marks]

Biostratigraphic column is a sequence of zones (1) characterized by particular fossil types (1)

2 marks

Zone fossil is a species that characterizes a zone

1 mark

Good zone fossils should be:

Rapidly evolving (or have narrow time range) (1), have a distinctive appearance (1), be abundant (1) and be geographically wide-ranging (1)

4 marks

[Block 10, Section 3.4]

*Discussion of **Glossopteris** and ammonites*

[Award 10 marks for points in bold type, and 2 marks from among the remaining points.]

Glossopteris land-based

1 mark

found in several continents (or continents listed in completed Table 11.1.2, Block 10 SF) (1) in rocks of same age (1)

(2 marks)

Unable to cross oceans (1) so suitable as evidence for continental drift (1)

2 marks

[Block 3, Section 11.2]

Unlikely to be abundant because

1 mark

Non-marine so unlikely to be permanently buried

(1 mark)

Leaves and/or stems would have rotted easily (or plants have poor preservation potential)

(1 mark)

Unsuitable as a zone fossil

1 mark

[Block 10, Section 2.1]

Ammonites are restricted to the Mesozoic Era (1) and vary in appearance (or shell shape) (1)

2 marks

So make suitable zone fossils

1 mark

Ammonites fully marine (1) so unsuitable as evidence of continental drift (1)

2 marks

Marks for writing skills

[Award two marks for each of the following aspects:]

Clarity of writing (correct spelling, sentence construction and lack of ambiguities)

2 marks

Conciseness – deduct one mark for each irrelevant point and, if the answer is still over-length once these points are removed, then deduct one mark for each 30 words over the 300 word limit.

2 marks

Coherence – appropriate use of paragraphs and points made in a logical sequence. The structure in the mark scheme shows one approach (zone fossils may be discussed before fossils as evidence for continental drift). Alternatively, students may integrate discussion of the named fossils within discussion of fossils as evidence of continental drift, and the use of fossils to establish the biostratigraphic column.

2 marks

Total marks

20 marks

Comments on activities

Activity 2.1

Task 1

See Figure 2.1.6. The full name of this trilobite species, incidentally, is *Acaste downingiae*. You should now add this name to your drawing.

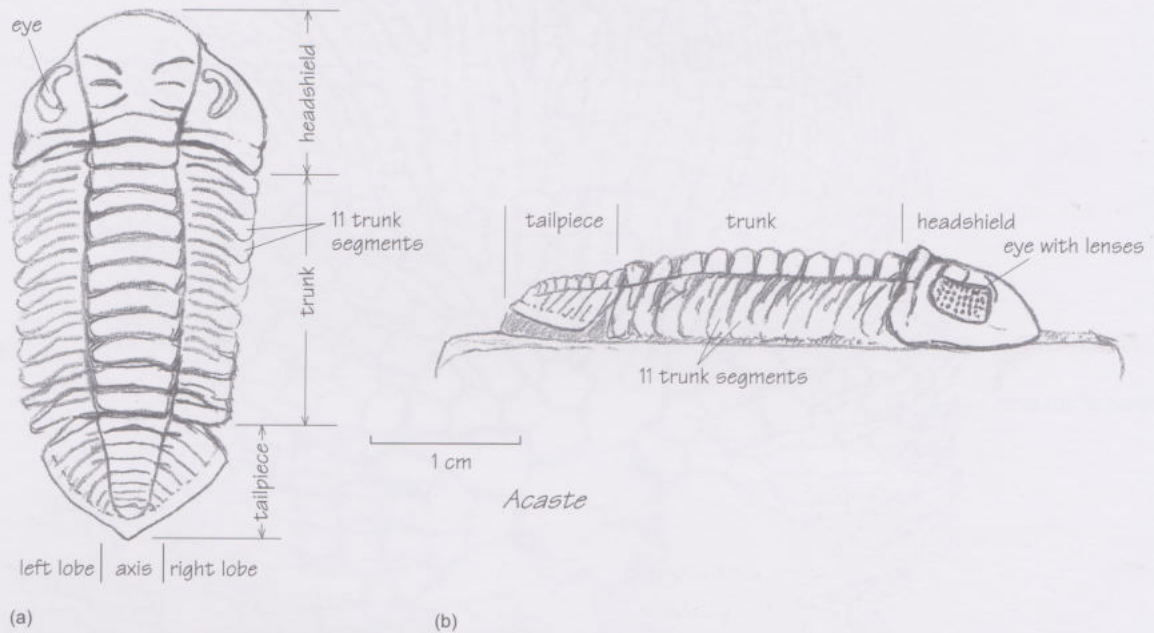


Figure 2.1.6 A completed Figure 2.1.1, for comparison with your own.

Task 2

See Figure 2.1.7. The full name of this coral species is *Acervularia luxurians*; you should now write this beside your drawing.

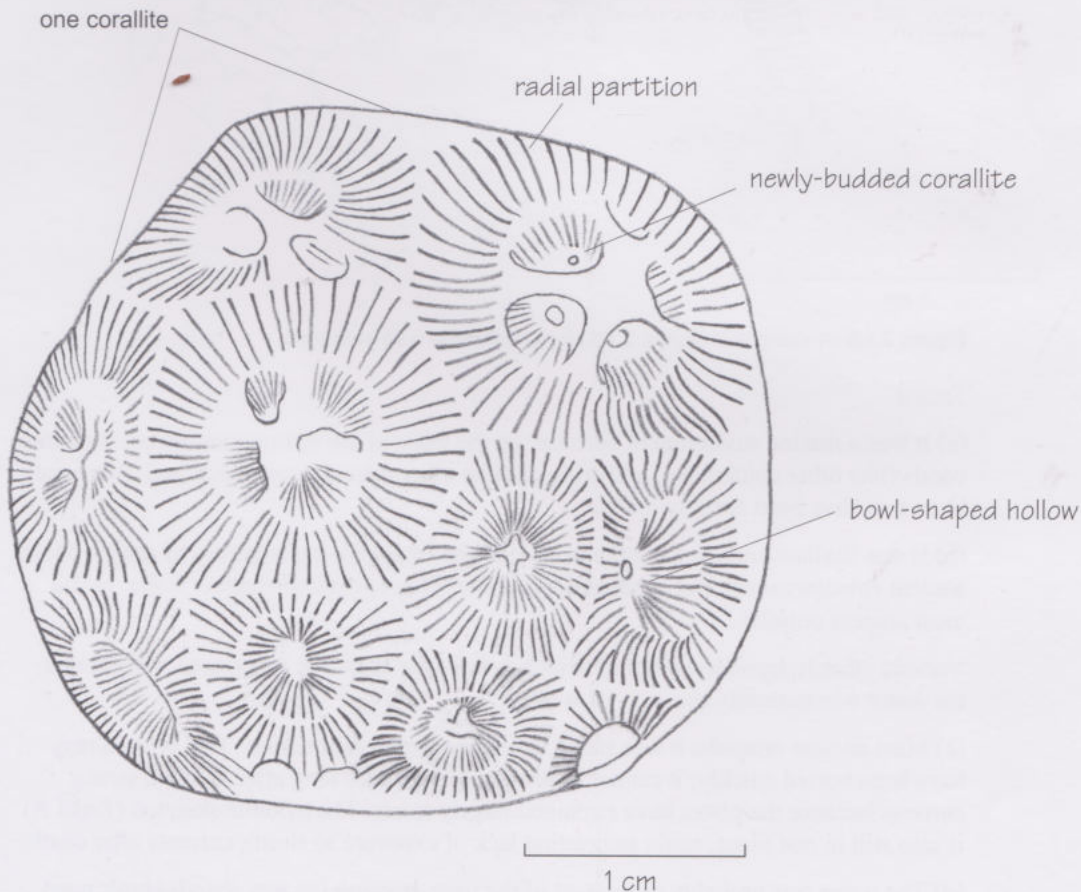


Figure 2.1.7 A completed Figure 2.1.4, for comparison with your own.

Task 3

See Figure 2.1.8. The full name of this crinoid species is *Gissocrinus typus*; you should now write this beside your drawing.

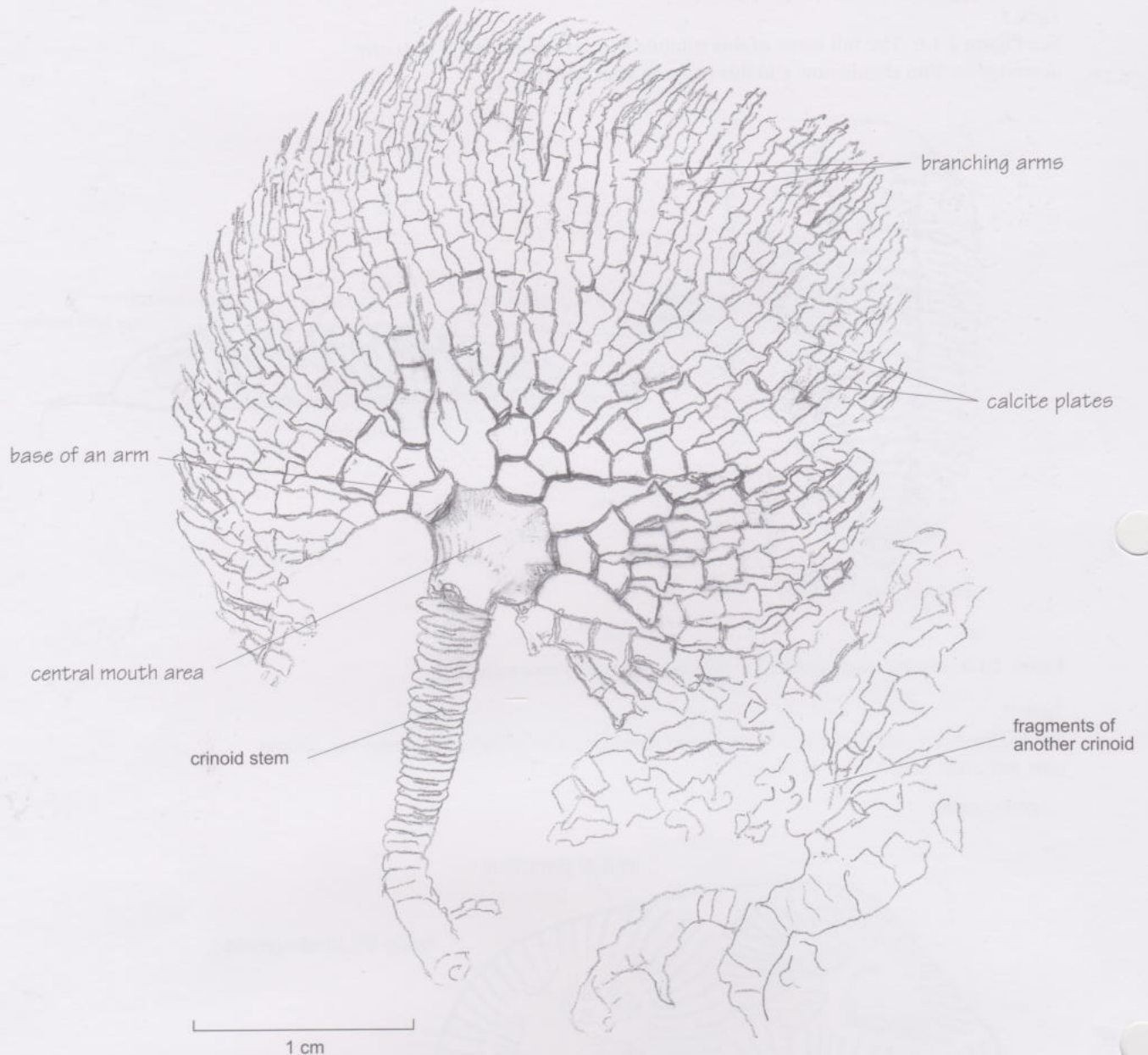


Figure 2.1.8 A completed Figure 2.1.5, for comparison with your own.

Task 4

(a) It was a marine environment because, on the basis of the information given, trilobites, corals (like other cnidarians), and crinoids (like other echinoderms, Section 2.2) are each known to have been entirely marine.

(b) It was shallow enough for there to be sufficient light for the trilobites to see by. Most ancient colonial corals, like modern ones, seem to have required shallow water, as did most ancient crinoids.

Various other independent lines of evidence from the Wenlock Limestone suggest that the water was normally about 5–10 m deep.

(c) Most ancient crinoids, it was stated, lived in current-swept areas. This crinoid may have been buried quickly; it cannot have been exposed for long after death to strong currents because the plates have remained largely intact. The trilobite skeleton (fossil A) is also still in one piece, again suggesting lack of exposure to strong currents after death.

(d) The water was probably clear most of the time, because (as was stated) corals need clear water, and muddy sediment kills off crinoids by clogging their feeding systems.

(e) By analogy with the preferences of modern coral colonies (and what is known of other ancient ones), it seems likely that the water was warm rather than cold.

This is supported by palaeomagnetic evidence (Block 3) showing that, at that time, Britain was about 30° south of the Equator.

Figure 2.1.9 is a reconstruction of a typical scene from a Wenlock Limestone environment. See if you can identify some trilobites, corals (colonies and isolated individuals), and crinoids.

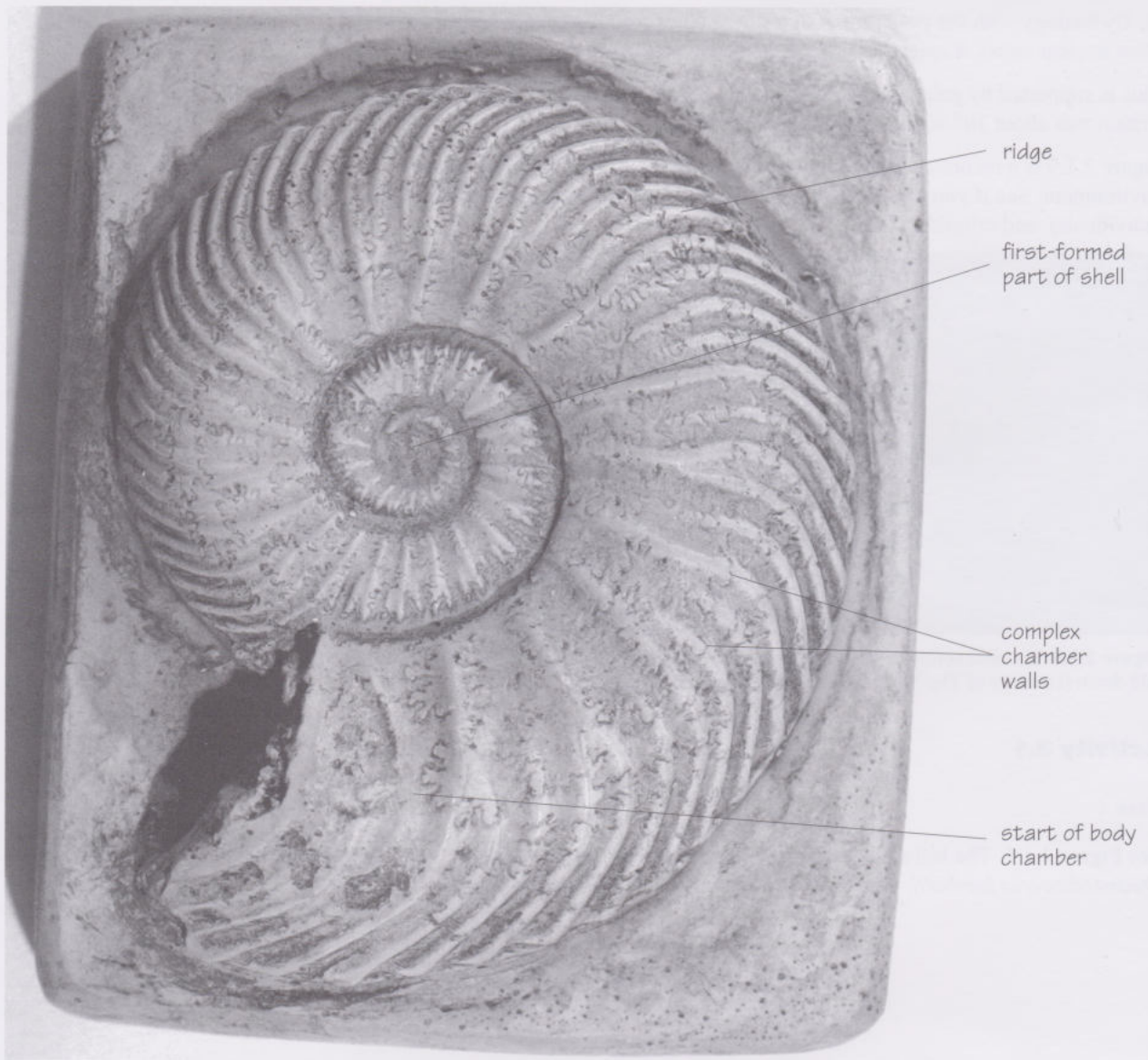


Figure 2.1.9 Reconstruction of a typical scene from the sea in which the Wenlock Limestone was laid down (courtesy of The Natural History Museum, London).

Activity 3.1

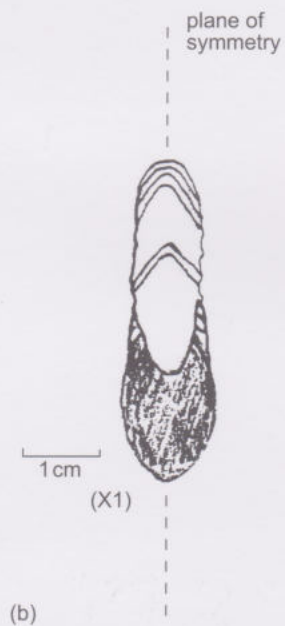
Task 1

See Figure 3.1.5. The full name of this ammonite species, incidentally, is *Quenstedtoceras lamberti*; you should now write this beside your drawing.



(a)

1 cm



(b)

Figure 3.1.5 A completed Figure 3.1.2, for comparison with your own.

Task 2

See Figure 3.1.6. The full name of this brachiopod species is *Cererithyris intermedia*; you should now write this beside your drawing.

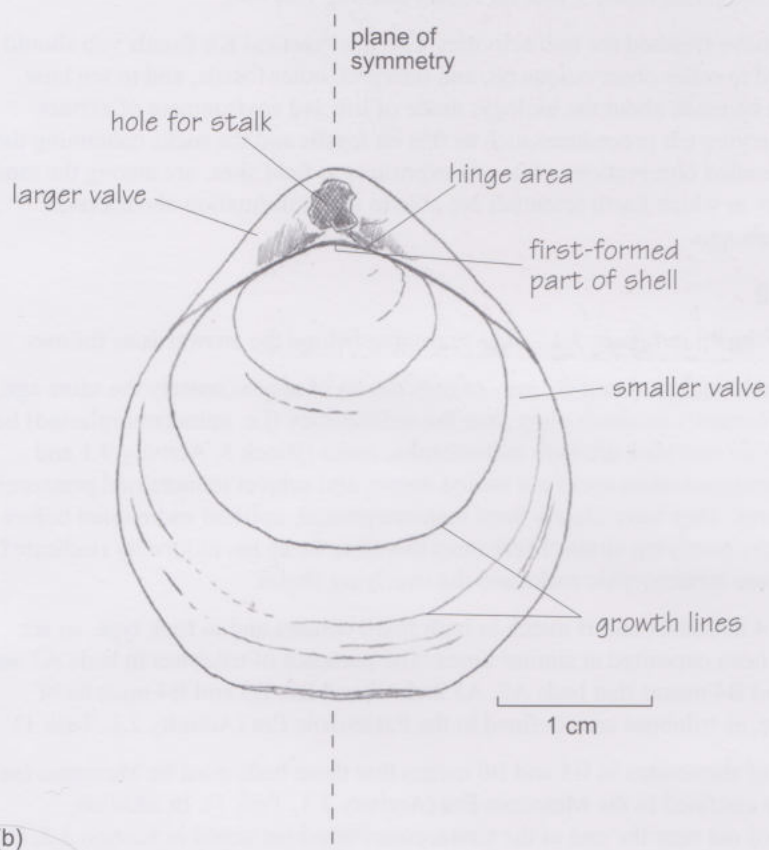
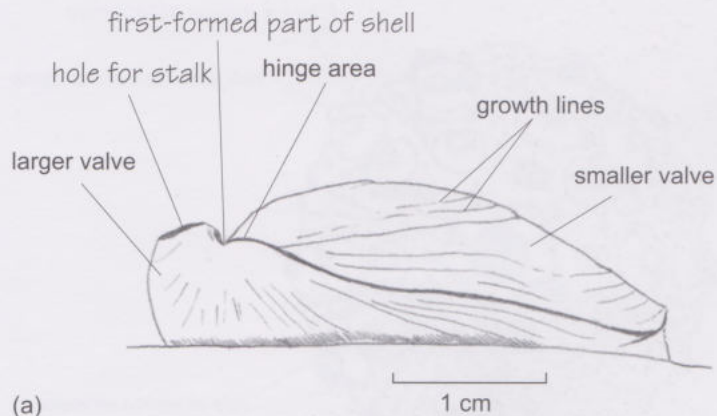


Figure 3.1.6 A completed Figure 3.1.3, for comparison with your own.

Task 3

See Figure 3.1.7. The full name of this echinoid species is *Hemicidaris intermedia*; you should now write this beside your drawing.

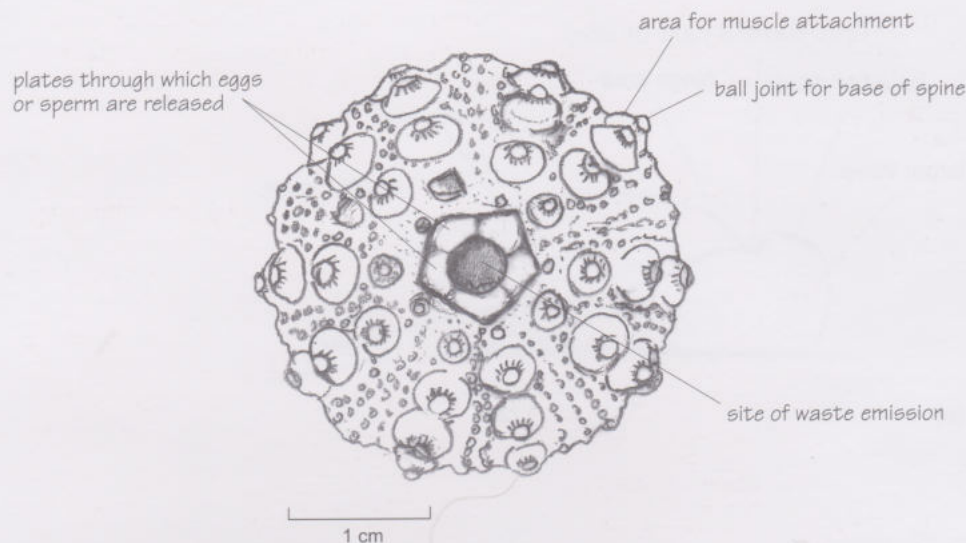


Figure 3.1.7 A completed Figure 3.1.4a, for comparison with your own.

Now that you have finished the two activities with the Practical Kit fossils you should be better equipped to make observations on, and interpret, other fossils, and to see how inferences can be made about the biology, mode of life and environment of extinct organisms. Carrying out procedures such as this on fossils and the rocks containing them, and making detailed observations of *in-situ* exposures at field sites, are among the most important ways in which Earth scientists are able to gain information about events millions of years ago.

Activity 3.2

The answer is shown in Figure 3.2.2. The reasoning behind the answer is as follows.

The metamorphic rocks A1 and B1 may or may not be of approximately the same age, but they must certainly be much older than the sedimentary (i.e. unmetamorphosed) beds A2 and B2. Schist and slate are both metamorphic rocks (Block 3, Activity 9.1 and Section 9.4) produced when rocks are buried deeply and subject to increased pressures and temperatures. They have clearly been metamorphosed, uplifted and eroded before the deposition of the overlying strata. There must therefore be an unconformity (indicated by U) between these metamorphic rocks and the overlying shales.

Beds 2, 3 and 4 in both A and B match in both fossil content and in rock type, so are likely to have been deposited at similar times. The presence of trilobites in beds A2 and A4, and B2 and B4 means that beds A2, A3 and A4 and B2, B3 and B4 must be of Palaeozoic age, as trilobites are confined to the Palaeozoic Era (Activity 2.1, Task 1).

The presence of ammonites in B5 and B6 means that these beds must be Mesozoic (as ammonites are confined to the Mesozoic Era (Activity 3.1, Task 1). In addition, plesiosaurs died out near the end of the Cretaceous Period (as stated in Section 3.2, Box 3.1), so this is additional evidence that B5 cannot be Cenozoic. There may be an unconformity (indicated by U?) between B4 and B5, although bed B4 might happen to be the latest Palaeozoic and bed B5 the earliest Mesozoic; more detailed identification of fossils present would reveal if this was the case.

Bed A5 (and the overlying bed, A6) must be of Cenozoic age, as A5 contains whale vertebrae, and whales originated only in the early Cenozoic (Figure 3.8 and Box 3.2). No Mesozoic rocks are therefore represented in A, so with Cenozoic rocks lying on Palaeozoic rocks there *must* be an unconformity between A4 and A5. Bed B7 (and the overlying bed B8) must also be Cenozoic as bed B7 contains whale vertebrae. There may therefore be an unconformity between B6 and B7 although bed B6 might happen to be the latest Mesozoic and bed B7 the earliest Cenozoic; again, more detailed identification of fossils present would reveal if this was the case.

In practice, the strata above and below an unconformity often dip at different angles (in addition to being of very different ages), because the underlying beds have been tilted, uplifted and eroded before the deposition of the overlying beds.

Note that each of the other fossil groups mentioned in columns A and B (i.e. brachiopods, crinoids, corals, bivalves and echinoids) occur in all three Phanerozoic eras, and are thus not diagnostic of any one era. Individual species, however, do have a much more restricted time-range.

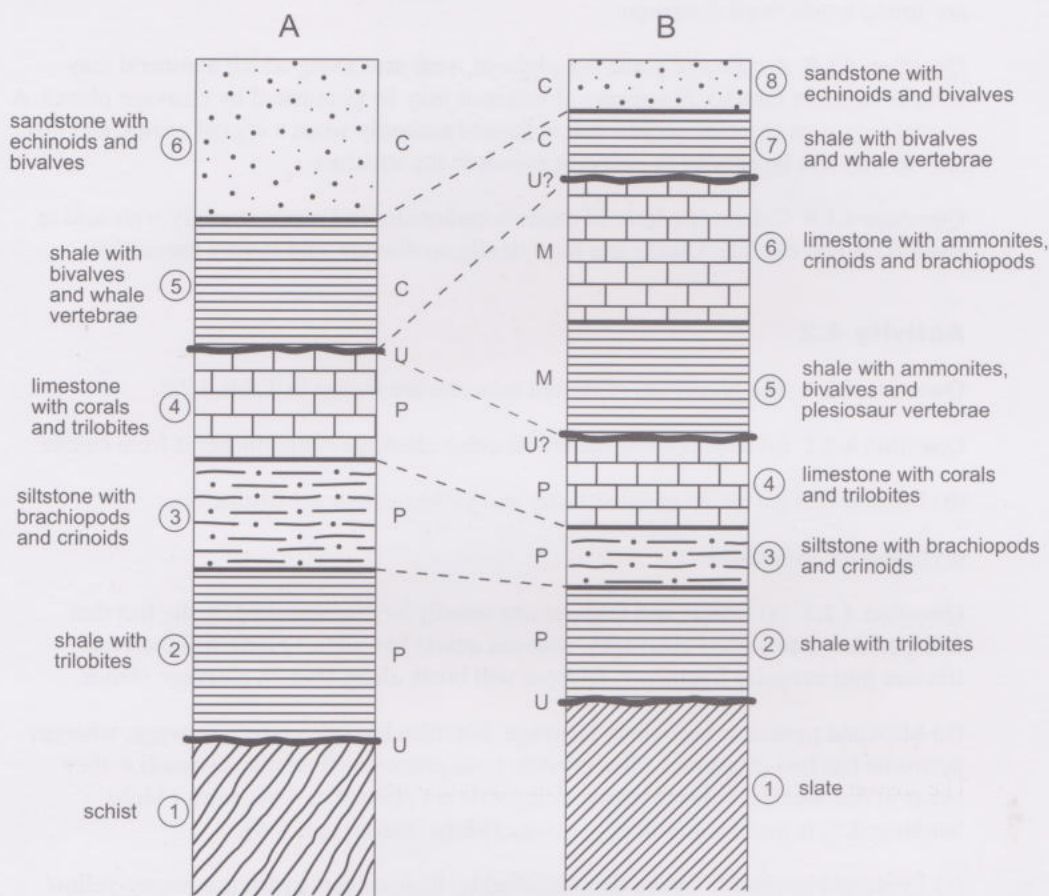


Figure 3.2.2 Completed version of Figure 3.2.1. P stands for Palaeozoic, M for Mesozoic, C for Cenozoic and U for unconformity.

Activity 4.1

Question 4.1.1 Although some minerals are associated with specific colours, many other minerals can have a range of colours, depending on the impurities in particular specimens (e.g. quartz can be colourless, pink, mauve, yellow or black).

Question 4.1.2 Ferromagnesian minerals are silicate minerals containing large proportions of iron and/or magnesium. They tend to be dark green or black in colour.

Question 4.1.3 Single crystal shapes can be broadly grouped into *equi-dimensional* (e.g. pyrite cubes), *prismatic* (e.g. pyroxene) or *tabular* (e.g. mica).

Question 4.1.4 Lustre is the name given to the appearance of a mineral's surface. Examples of lustre include *metallic* (e.g. pyrite), *glassy* (e.g. quartz) and *earthy* (e.g. haematite).

Question 4.1.5 Mohs' scale is a list of ten common minerals, ranked in order of increasing hardness, from 1 (talc) to 10 (diamond). Mohs' scale can be used to indicate the approximate hardness of a mineral. A particular mineral will be scratched by all minerals that have a higher value on Mohs' hardness scale, and, in turn, will scratch all minerals with lower hardness values.

Question 4.1.6 Diamond and graphite have the same chemical composition, but very different hardnesses because they have very different crystal structures. The diamond structure has strong bonding in all directions. The graphite structure shows strong bonding within two-dimensional sheets, but the bonding between successive sheets is very weak, so that sheets can slide over each other easily, making it a very soft mineral.

Question 4.1.7 The mica crystal structure contains definite planes of weakness, along which the mineral can split. The quartz structure shows no such planes of weakness; there are strong bonds in all directions.

Question 4.1.8 A cleavage plane is a plane of weakness along which a mineral may split, or separate (crack). Fragments of minerals may be terminated by cleavage planes. A crystal face is an external surface that is formed naturally when a crystal grows, and this may or may not be parallel to cleavage planes in the structure.

Question 4.1.9 Calcite is a form of calcium carbonate, and reacts strongly with acid to produce carbon dioxide. Quartz is a form of silicon dioxide, and is very unreactive.

Activity 4.2

Question 4.2.1 The properties of the ten minerals are shown in Table 4.2.2.

Question 4.2.2 (a) Mineral A is halite; the cubic cleavage distinguishes it from calcite.

(b) Mineral B is pyrite; its metallic lustre and yellow colour are distinctive.

(c) Mineral C is feldspar.

Question 4.2.3 (a) Quartz and feldspar can usually be distinguished by the fact that feldspar shows two good cleavages, whereas quartz has none. Quartz will therefore fracture into irregular fragments; feldspar will break along smooth cleavage planes.

(b) Mica and pyroxene both show cleavage, but mica has one perfect cleavage, whereas pyroxene has two cleavages. Mica crystals have pronounced tabular shapes (i.e. they occur in flat sheets), whereas pyroxene crystals are prismatic. Also, mica (Mohs' hardness 2.5) is much softer than pyroxene (Mohs' hardness 5.5–6).

(c) Pyrite and haematite can be distinguished by their colour: pyrite is a brassy-yellow colour, whereas haematite is brown or black.

(d) Calcite reacts strongly with acid, whereas halite does not. Halite and calcite are both soft minerals with three excellent cleavages. However, fragments of halite are cube-shaped, whereas fragments of calcite are rhomb-shaped.

Table 4.2.2 Completed version of Table 4.2.1. The main physical and chemical properties of some common rock- and ore-forming minerals.

Mineral	Classification	Composition	Colour	Lustre	Cleavage	Hardness
quartz (rock crystal)	silicate (framework structure)	SiO ₂	colourless — can be pink, mauve or smoky	glassy	none (irregular fracture)	7 (harder than steel)
feldspar	silicate (framework structure)	alkali, (K,Na)AlSi ₃ O ₈ plagioclase, from NaAlSi ₃ O ₈ to CaAl ₂ Si ₂ O ₈	generally colourless to white (but can be other colours)	dull to glassy	two good cleavages	6–6.5
mica	silicate (sheet structure)	pale (muscovite) KAl ₃ Si ₃ O ₁₀ (OH) ₂ dark (biotite) K(Fe,Mg) ₃ AlSi ₃ O ₁₀ (OH) ₂	brown, black or silvery	glassy	one perfect cleavage	2.5
pyroxene	silicate (chain structure)	(Ca,Mg,Fe) ₂ Si ₂ O ₆	dark green to black	dull to glassy	two cleavages at 90°	5.5–6
garnet	silicate (isolated groups)	(Ca,Fe,Mg) ₃ (Al,Fe) ₂ Si ₃ O ₁₂	variable — deep red, brown, black, green	glassy	none (brittle fracture)	7
olivine (peridot)	silicate (isolated groups)	(Mg,Fe) ₂ SiO ₄	pale to dark green	glassy	none (irregular fracture)	6.5–7
calcite	non-silicate — carbonate	CaCO ₃	colourless (but can be tinted yellow or pink)	glassy	three perfect cleavages, causing crystals to break into rhomb-shaped fragments	3
halite (rock salt)	non-silicate — halide	NaCl	colourless (but can be tinted)	glassy	three perfect, cleavages causing crystals to break into cubes	2
pyrite (fool's gold)	non-silicate — sulfide	FeS ₂	brassy-yellow	metallic	poor (brittle fracture)	6–6.5
haematite (bloodstone or kidney ore)	non-silicate — oxide	Fe ₂ O ₃	brown-black	metallic to earthy	poor (brittle fracture)	5–6

Activity 5.1

Task 1

Individual grains of both basalt (Specimen 5) and granite (Specimen 6) are crystals that are held together tightly because they are intergrown and interlocking — this is a characteristic of igneous rock textures. The crystal grains don't appear to be fragmentary — they are not worn or broken fragments of rock. Also, grains don't break away easily, nor do broken surfaces tend to pass around grains, as is common in many sedimentary rocks. In fact, grains of the same mineral often have similar crystal shapes, and where the rock has been broken, individual crystals are often split, sometimes revealing cleavage planes.

The crystals of the granite sample are randomly oriented and randomly distributed, and this is characteristic of an igneous, rather than a metamorphic, texture. Recall that metamorphic rocks show a tendency for the crystals to be aligned, and to have a banded structure. Some of the flat crystals in the basalt sample may show some alignment, but there is no banding. In this case the alignment is not metamorphic — the rock has not been affected by pressure; in fact, these crystals were aligned because the magma was *flowing* prior to solidification.

Task 2

(a) The colour of the basalt is very dark throughout; the granite is generally paler, but more variable in colour (white, grey and black).

Much of the basalt is very fine-grained; most crystals are too small to measure the grain size by eye, but some crystals (long thin ones and broad chunky ones) are up to 10 mm in length. The granite, by contrast, is coarse-grained throughout, with most grains 2–5 mm across, and a few up to 20 mm.

(b) The *colour* depends on the mix of minerals present in the rock. Almost all of the minerals in the basalt are dark grey or dark green to black in colour (although there are some paler crystals on and close to weathered surfaces), whereas the minerals in the granite are white, grey and black. The *grain size* is a reflection of the rate of cooling during crystallization and provides an indication of the way crystallization occurred (Block 3, Activity 9.1). Thus the basalt, with many very fine-grained crystals, cooled rapidly as an *extrusive* rock and crystallized at the Earth's surface. The presence of the larger crystals in the basalt will be explained in Section 5.1.1). The coarse-grained granite cooled slowly as an *intrusive* rock, crystallizing deep beneath the Earth's surface.

Activity 5.2

Task 1

The three types of mineral crystal present in granite have the following properties:

Type 1: grey, glassy, granular, 1–4 mm diameter, no cleavage.

Type 2: white, more box-shaped, 2–10 mm across, with reflecting cleavage planes. (You may be able to see two sets of cleavages.)

Type 3: black (some silvery) flakes, 1 mm across, shiny surfaces, which represent cleavage planes.

These three minerals are quartz, feldspar and mica, respectively. You should find that the properties listed above are in accord with the properties you have summarized in Table 4.2.1.

Task 2

(a) The chemical formulae for the main minerals in granite and basalt are included in Table 4.2.1, and are as follows:

Granite:	alkali feldspar	$(\text{K}, \text{Na})\text{AlSi}_3\text{O}_8$
	quartz	SiO_2
	dark mica (biotite)	$\text{K}(\text{Fe}, \text{Mg})_3\text{AlSi}_3\text{O}_{10}(\text{OH})_2$
Basalt:	plagioclase feldspar	$\text{CaAl}_2\text{Si}_2\text{O}_8$
	pyroxene	$(\text{Ca}, \text{Mg}, \text{Fe})_2\text{Si}_2\text{O}_6$

(b) On the basis of these mineral compositions, the granite will contain more potassium (K, in alkali feldspar and dark mica) and sodium (Na, in alkali feldspar). Silicon (Si) is present in all the silicate minerals but, owing to the high proportion of quartz (SiO_2) present, it must be most abundant in the granite. The basalt will contain more calcium (Ca, in plagioclase feldspar and pyroxene). There is only a small amount (perhaps 10%) of biotite mica in the granite, and this is the only mineral containing iron (Fe) and magnesium (Mg) that is present in the granite; on the other hand, there is abundant pyroxene in the basalt, so there's likely to be much more Fe and Mg in the basalt than in the granite.

Activity 5.3

(b) When you come to a reference to an earlier block you can respond in various ways.

- If you are confident that you understand the topic referred to, you may decide that you don't need to look back.
- If you are unsure of the topic referred to, then we recommend that you look back at the earlier material. Just looking back, and scanning or rereading the material referred to, will provide useful revision and reinforcement.
- You can enhance this revision and reinforcement by doing something active with the material, rather than just reading it again. For example, you could:

- summarize in the margin of Block 10 the important points that are made in the section/figure/box that was referred to;
- note the definition of a term referred to;
- sketch a relevant diagram in the margin as a reminder of the link;
- draw a spray diagram to summarize links between important ideas;
- use a highlighter pen to identify key references.

All of these active ways of revising will help to reinforce your memory of the earlier material and its links to the material that you are currently studying.

(c) Producing notes and summaries, writing out definitions, and sketching diagrams of various kinds are equally useful as ways of preparing for revision of this block. If there is one method that you find most effective, then you should concentrate on that, but you may find that it is better to use a mix of methods. As you study Sections 6-10, keep these options in mind.

Activity 6.1

Task 1

When we tried this experiment, we observed that the soil (effectively a mixture of sediment grains) settled as the water came to rest. The larger chunks of material settled almost immediately, and the smaller grains settled soon after. It took longer for very fine grains to settle. A murky-looking solution remained above the sediments.

Task 2

The types of sediment grain you see depend on the nature of your local soil. Some soils are more stony or sandy, others are more muddy. The following description was written by a member of the Course Team, who used what was thought to be a fairly average soil.

The larger grains settled to the bottom of the jar with layers of progressively finer material above. The coarser material (stones) may be described as pebbles (larger than 2 mm). The finer material immediately above it may be described as sand (less than 2 mm but greater than 0.5 mm). The very fine material at the top, brownish-grey in colour, is mud, and is likely to be composed largely of clay minerals, some of which are so fine-grained that they took a long time to settle out of suspension. The water was very cloudy at first, then very discoloured, and eventually became almost clear and colourless. Finally, there is some woody plant material that floated because it's less dense than water.

Task 3

A sample sketch is shown in Figure 6.1.1. Note how the labelling conveys the important information in the description above, and is much easier to comprehend. Your diagram, and the way it is labelled, will differ from this one because your soil will be different, but you should check that you have labelled the important features that you observed.

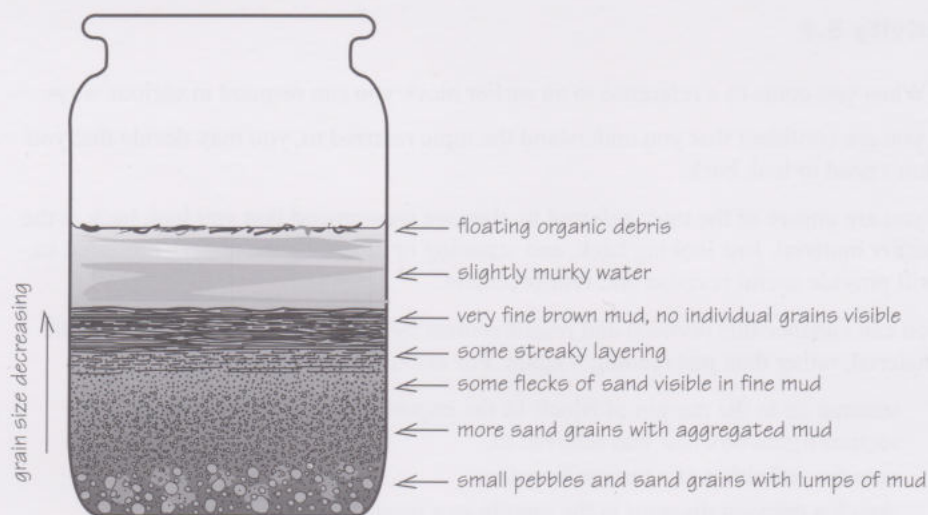


Figure 6.1.1 A sketch showing settled sediment in a jar.

Task 4

The finest material from the top of your sediment is probably like sludge, and you are unlikely to be able to distinguish individual grains. It is probably mud, made largely of clay. The coarsest material may include pebbles, which may be rounded or angular and made of rock and mineral fragments. Usually pebbles have surfaces that are abraded and it may be difficult to see exactly what they are made of. Some sand-sized grains may be recognizable as particular minerals; for example, there may be translucent glassy grains of quartz, which may be rounded or angular; there may be pale-coloured but opaque grains of feldspar; and there may be silvery flakes of mica.

Activity 6.2

Task 1

- Physical and chemical weathering break down rocks to produce sediment grains.
- Grains move downstream by rolling, or by bouncing, or they are carried in suspension.
- River sediments typically contain a wide range of grain sizes and minerals, whereas beach sediments contain a much narrower range of grain sizes and fewer minerals, and quartz frequently dominates.
- Wind-blown grains are normally well-rounded and their surfaces are very finely pitted. Water-lain grains are more angular and have a glassy appearance.

Task 2

The calculated mass percentages for each sieve are shown in Table 6.2.2.

Table 6.2.2 Completed version of Table 6.2.1. Grain-size data from a sieving experiment.

Sieve size/mm	Mass in sieve/g	% of total mass
4	1.0	2.1
2	1.4	2.9
1	4.8	10.1
0.5	7.1	14.9
0.25	14.5	30.4
0.12	9.4	19.7
0.6	7.3	15.3
pan	2.2	4.6
total	47.7	100.0

The histogram for these data is shown in Figure 6.2.3. Because the sand is distributed over a large number of sieves, this histogram represents a poorly-sorted sediment.

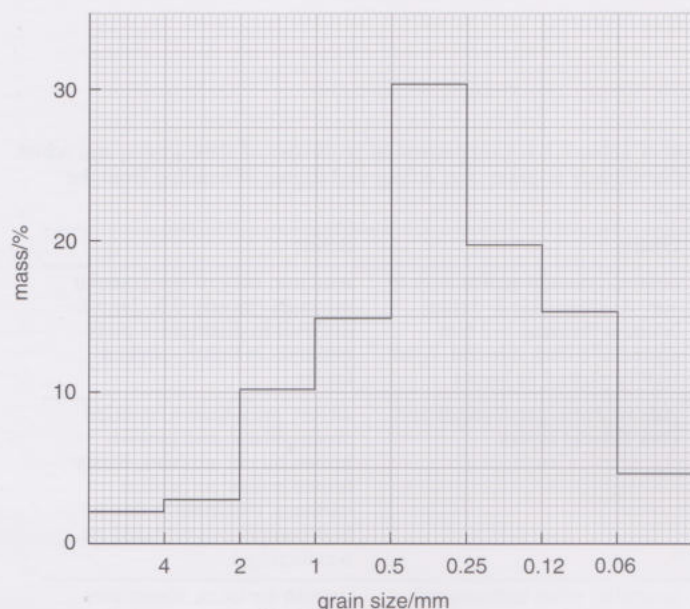


Figure 6.2.3 Sediment grain-size histogram based on data in Table 6.2.2.

Task 3

(a) Of the histograms shown in Figure 6.2.2a: (i) is likely to be the river sand as it has a poorly-sorted distribution; (ii) is likely to represent a desert sand, as it is a very well-sorted distribution; (iii) is likely to be a beach sand as it is a fairly well-sorted distribution.

(b) Matching grain-size histograms (Figure 6.2.2a) with cumulative frequency distribution graphs (Figure 6.2.2b): a(i) and b(iii) represent poorly-sorted distributions (a river sand); a(ii) and b(i) are very well-sorted (a desert sand); and a(iii) and b(ii) are fairly well sorted (a beach sand). Note that a well-sorted sand has a narrow spread on the histogram — the sand ends up in two or three sieves — and a steep cumulative frequency distribution graph. Conversely, a poorly-sorted sand has a broader spread on the histogram, and the cumulative frequency graph is less steep.

Task 4

Grains can be removed from the sandstone with a metal instrument more easily than from the igneous rocks but are too tightly held to be prised off with a fingernail. The grains range from almost 2 mm in diameter to a size that is too small to be measured (much less than 0.1 mm in diameter). The finer material is soft and crumbly and much of it is clay. The sand grains are glassy and are mostly quartz. There is not a wide range of sand-size grains as nothing is greater than 2 mm in diameter, but there is a considerable amount of very fine material. Therefore, the sediment has a greater spread of grain sizes than a desert sand, or even a beach sand; the spread is similar to that for a river sand.

Looking at the rock with a hand lens, individual quartz grains are often glassy and frequently angular in shape, and in places the grains are closely packed together. Sometimes they are surrounded by white or pale brown powdery material, which is soft and largely clay. The angular and glassy quartz grains are much like those transported by water in the DVD-video sequence 'A story of sand'; they are not well-rounded and 'frosted' wind-blown grains. There are also lots of holes visible in the structure of the rock, especially on a cut surface. A drop of water rapidly soaks into the rock, indicating that there is a lot of open space between grains.

Activity 7.1

Task 1

Table 7.1.2 Completed version of Table 7.1.1. Comparison of properties of slate, gneiss and schist. (Your sample of schist may differ slightly in grain size, colour and degree of banding from the typical example described here.)

Property	Slate	Gneiss	Schist
grain size	fine; surfaces are smooth and most grains are too small to distinguish; only larger dark flecks (0.5 mm max) visible	coarse; granular grains easy to see. Average size 3–5 mm. Some individual 1–2 mm grains of a dark mineral. Also tightly packed in layers	medium; easy to see granular minerals (mostly 0.5–2 mm); difficult to distinguish platy minerals in tightly-packed layers
colour	pale grey with dark flecks, fairly uniform	pale (creamy/grey) bands and dark (black) layers	silvery grey-brown, mottled cream, black, and pinkish brown on cut surfaces. Rusty brown colour on broken surfaces. (Staining is due to iron compounds released on weathering.)
texture	a scaly effect is apparent where lighting highlights edges to thin layers with flat surfaces. Not possible to see arrangement of fine grains. (Breakage along parallel surfaces is along cleavage planes.)	irregular, often lens-shaped bands of pale granular minerals, and dark sinuous and discontinuous bands of platy minerals.	uneven surfaces, sometimes crinkly or corrugated, but fairly smooth, with a reflective sheen due to planar alignment of medium-coarse grained platy minerals. In some samples layers of dark and light minerals may be present (as in gneiss)
minerals	minerals unrecognizable. (Mainly fine-grained mica that you would see as a slightly reflective sheen in hand specimen.)	grey quartz, white feldspar, dark (biotite) mica.	mainly silvery and dark mica flakes, glassy quartz; sometimes pinkish-brown garnet

Task 2

The grain sizes of the three rocks vary, and so does the nature of the layering. In order of increasing grain size you have slate, schist, and gneiss. At the same time, the layering becomes more uneven — flat in the slate (Figure 7.3a), uneven in the schist (Specimen 4), and undulating in the gneiss (Figure 7.3b) — and there is greater separation between layers along which the rocks would tend to break. In Section 7.1.2 you will see how these changes in character reflect an increase in grade of metamorphism.

Activity 7.2

Figure 7.2.2 is a completed version of the rock cycle for Tasks 1 and 2.

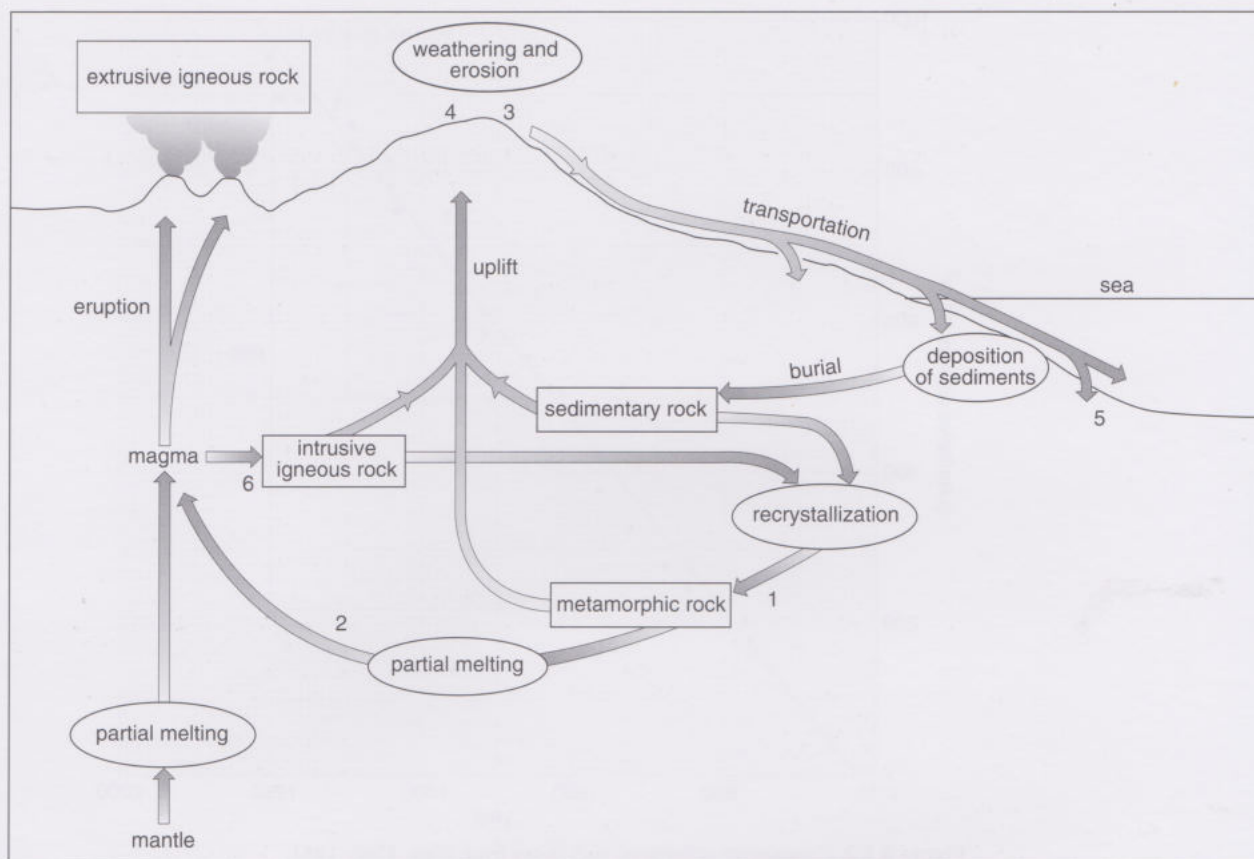


Figure 7.2.2 The completed rock cycle for Activity 7.2.

Activity 8.1

Task 1

The cumulative volume data are shown in Table 8.1.2. Each cumulative volume is the sum of the volume of lava produced that year and the previous value of the cumulative volume.

Task 2

A graph of the cumulative volumes is shown in Figure 8.1.2, with a best-fit line drawn through the data points.

The gradient of the best-fit line was determined using the construction lines drawn on the graph, and is

$$\text{gradient} = \frac{\text{rise}}{\text{run}} = \frac{(970 - 220) \times 10^6 \text{ m}^3}{(1950 - 1800) \text{ y}}$$

$$= \left(\frac{750}{150} \right) \times 10^6 \text{ m}^3 \text{ y}^{-1} = 5.0 \times 10^6 \text{ m}^3 \text{ y}^{-1} \text{ to two significant figures}$$

The gradient has units of volume per unit time; in other words it is a measure of the rate of growth between 1758 and 1951. So, averaged over the period between 1758 and 1951, Etna grew at a rate of about $5.0 \times 10^6 \text{ m}^3 \text{ y}^{-1}$, or $5.0 \times 10^{-3} \text{ km}^3 \text{ y}^{-1}$.

Table 8.1.2 Completed version of Table 8.1.1. Volumes of lava flows from eruptions of Etna, 1766–1951.

Year of eruption	Volume of lava flow / 10^6 m^3	Cumulative volume / 10^6 m^3
1766	106	106
1780	15	121
1793	80	201
1809	19	220
1812	25	245
1819	31	276
1832	50	326
1843	50	376
1853	128	504
1865	46	550
1879	36	586
1886	56	642
1892	100	742
1908	3	745
1910	34	779
1911	36	815
1923	45	860
1928	30	890
1942	2	892
1947	4	896
1949	3	899
1951	50	949

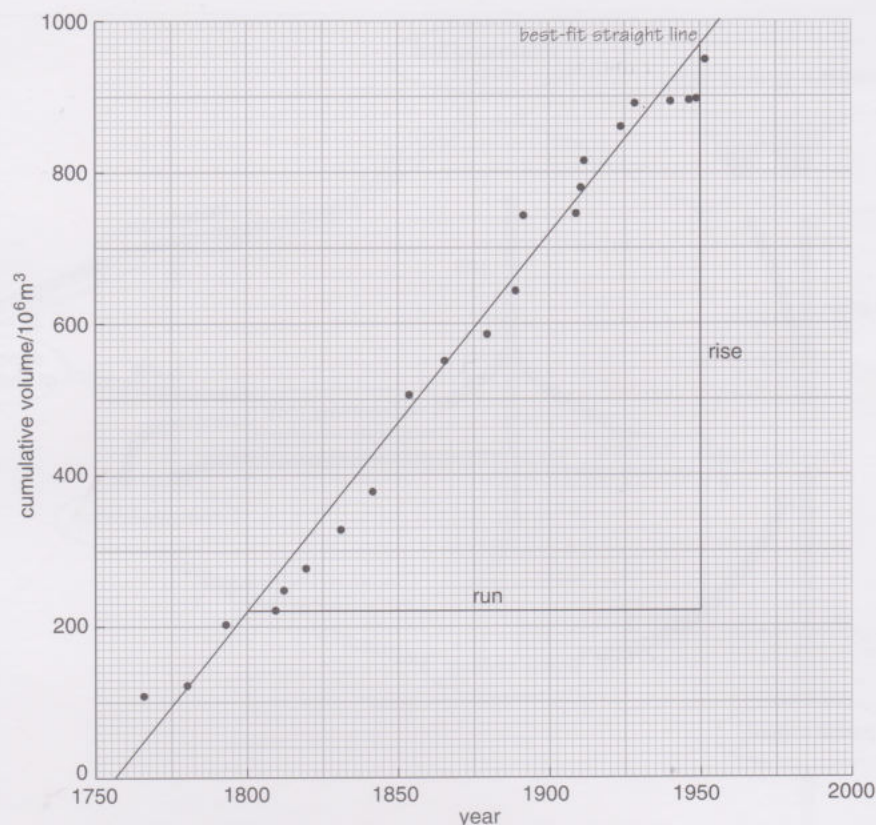


Figure 8.1.2 Cumulative volume of lava flows from Etna, 1766–1951.

Activity 8.2

If you had difficulty answering any of these revision questions, you may wish to look back at the sections of earlier blocks that are referenced after the answers.

(a) The terms parent and daughter are applied to the nuclides (or atoms) involved in a radioactive decay process. The unstable nuclide that undergoes radioactive decay is known as the parent nuclide, and the nuclide that is produced in the decay process is known as the daughter nuclide (Block 7, Activity 5.1).

(b) The superscript 235 is the *mass number*, represented by the symbol A , and this is the total number of neutrons and protons in the nucleus of an atom of this isotope. The subscript 92 is the *atomic number*, represented by the symbol Z ; this is the number of protons in the nucleus. Recall that all isotopes of a particular element have the same atomic number Z , but they can have different mass numbers (Block 6, Section 14.4; Block 7, Section 5.1).

(c) The five types of decay are shown in Table 8.2.2. We have italicized the information in the cells that you were asked to complete (Block 7, Section 5).

Table 8.2.2 Completed version of Table 8.2.1. The different types of radioactive decay process.

Decay process	What is emitted?	How does the nucleus change?
alpha	<i>alpha particle ($\frac{4}{2}\text{He}$ nucleus)</i>	A decreases by 4, Z decreases by 2
beta-minus	<i>electron and electron antineutrino</i>	A is unchanged, Z increases by 1
beta-plus	positron and electron neutrino	A is unchanged, Z decreases by 1
electron capture	electron captured and electron neutrino emitted	A is unchanged, Z decreases by 1
gamma	<i>gamma-ray photon</i>	<i>Both A and Z are unchanged</i>

Each of these decay processes releases energy, and since long-lived radioactive isotopes, such as $^{235}_{92}\text{U}$, $^{238}_{92}\text{U}$, $^{232}_{90}\text{Th}$ and $^{40}_{19}\text{K}$, occur naturally in the rocks of the Earth's crust and mantle, they contribute to the internal energy that keeps the Earth geologically active.

(d) The half-life of a radioactive isotope is the time taken for half of the original number of parent atoms to decay to daughter atoms. Half-lives range from 10^{-12}s (the somewhat

arbitrary limit below which we described nuclides as ‘impossible’ in Block 7, Activity 5.1) up to times much greater than the age of the Universe, about 10^{11} years, in which case we regard a nuclide as stable.

(e) (i) 3 days is one half-life, and so half of the original number of parent atoms will have decayed. So $1\,000 \times \frac{1}{2} = 500$ parent atoms will remain after 3 days. (Remember though that the decay process is random, so that there is some uncertainty in this number; for example, there may be 520 remaining, or perhaps only 480.)

(ii) 9 days is three half-lives, and so the number of parent atoms remaining will be $1\,000 \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = 1\,000 \times \frac{1}{8} = 125$.

(iii) 36 days is equivalent to 12 half-lives, and so the number of parent atoms remaining will be only

$$1\,000 \times \left(\frac{1}{2}\right)^{12} = \frac{1\,000}{4\,096} = 0.24$$

However, atoms can exist only as whole entities and so it is likely that there will be either 1 or 0 parent atoms remaining after 36 days.

(f) Radioactive isotopes decay at a constant rate that is unaffected by external conditions. They therefore meet the important criteria for determining the absolute age of rocks noted at the end of Section 8.3 — ‘a natural process that occurs inside rocks at a constant rate and which is independent of external influences’.

Activity 8.3

Task 1

The data are shown in Table 8.3.2. The values of D/P in the last column are the same as those that would be calculated using Equation 8.4. For example, after five half-lives have elapsed, i.e. $n = 5$, then

$$D/P = 2^5 - 1 = 32 - 1 = 31$$

which is the value shown in Table 8.3.2.

Table 8.3.2 Completed version of Table 8.3.1. Numbers of atoms of parent and daughter isotopes during radioactive decay.

Number of half-lives elapsed, n	Number of parent atoms, P	Number of daughter atoms, D	D/P
0	1 024	0	0
1	512	512	1
2	256	768	3
3	128	896	7
4	64	960	15
5	32	992	31
6	16	1 008	63
7	8	1 016	127
8	4	1 020	255
9	2	1 022	511
10	1	1 023	1 023

Task 2

(a) Figure 8.3.3 shows a graph of P against n , and (b) Figure 8.3.4 shows a graph of D/P against n . Note that the second graph describes *any* radioactive decay process, whether the half-life is 1 s or 1 Ma. Whatever the half-life, after three half-lives have elapsed only $\frac{1}{8}$ of the parent atoms will remain, and the D/P ratio will be 7.

(c) The graph in Figure 8.3.3 shows that the number of parent atoms drops rapidly at first, and then at progressively slower rates, but for each half-life interval the number drops by a factor of $\frac{1}{2}$. The second graph, Figure 8.3.4, shows that the value of D/P increases slowly at first, and then progressively faster, as the number of daughter atoms increases and the number of parent atoms decreases.

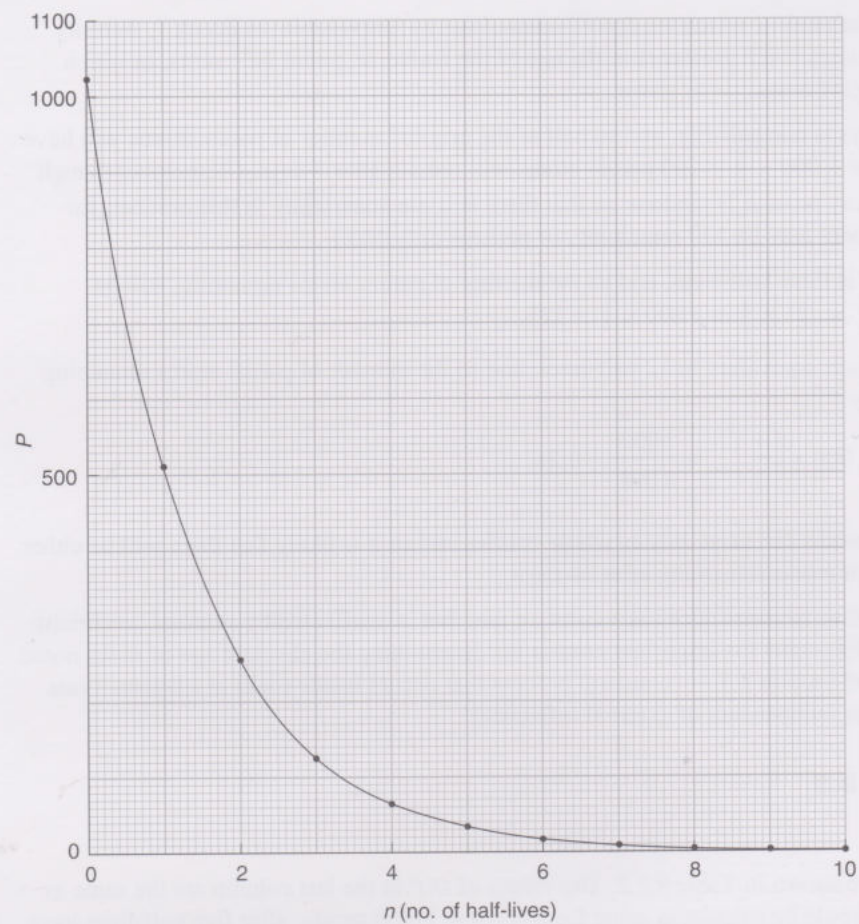


Figure 8.3.3 The change in the number of radioactive parent atoms with time.

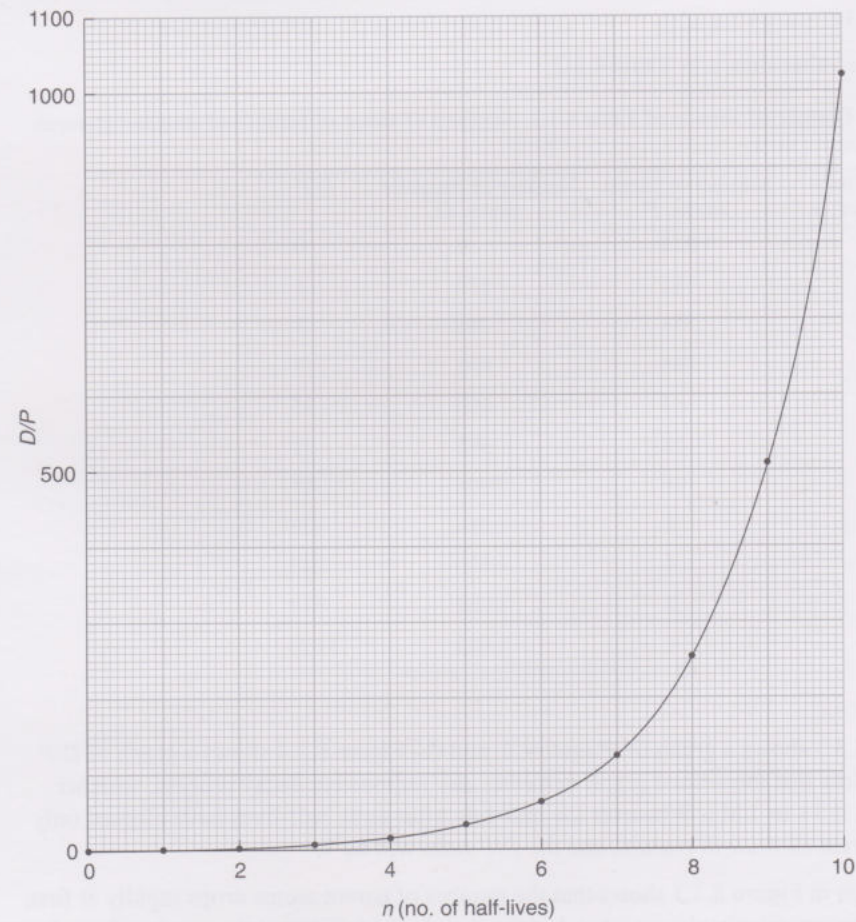


Figure 8.3.4 The change in the value of D/P with time.

Activity 8.4

Task 1

- (a) A–E is the older sedimentary series. This series was eroded down to what is shown as a horizontal line in Figure 8.4.1a before the series F–I was deposited.
- (b) J is the older, because it was eroded before the second sedimentary series was deposited, and K must have been deposited after H.
- (c) The sequence is: A–E, the first sedimentary series; J, the intrusion of the dyke; F–I, the second sedimentary series; K, intrusion of the sill.
- (d) An unconformity — an ancient erosion surface.
- (e) If K were a lava flow then it would represent a break in time between the deposition of H and I, and so it would be older than I.

Task 2

- (a) From Figure 8.6, a D/P ratio of 0.70 is equivalent to 0.77 half-lives. Since the half-life of $^{235}_{92}\text{U}$ is 704 Ma, 0.77 half-lives is equivalent to $0.77 \times 704 \text{ Ma} = 540 \text{ Ma}$, to two significant figures.
- (b) The granite cuts across the beds A–D, and these sediments have been metamorphosed where they are in contact with the granite. So the granite must be *younger* than these beds.
- (c) There is no evidence of metamorphism where the granite is in contact with the sediments, and there are pebbles of granite in the overlying sediments. The upper surface of the granite is therefore a major unconformity. The granite must originally have been intruded into crustal rocks. Erosion removed these rocks and cut into the granite to leave a huge granite hill. Sediments X and Y accumulated against the sides of this hill, and finally Z completely covered it. So the granite is *older* than the beds X–Z.
- (d) The sediments in Figure 8.4.2a are older than the granite. They are therefore older than 540 Ma, approximately the age of the Cambrian faunal explosion. Consequently, they are unlikely to contain fossils. By contrast, the sediments in Figure 8.4.2b are younger than the granite and so younger than 540 Ma. These sediments therefore could contain fossils, but only if they were deposited in a marine environment. Remember, there were no land animals or plants before the Devonian, about 400 Ma ago (Section 3.1).

Activity 9.1

- (a) If you live in the British Isles, your answer to this question could be anything from mid-Precambrian to Tertiary and early Quaternary, as far as age is concerned. The rock type could be any one or more of the various igneous, sedimentary or metamorphic rocks indicated. The geology of these islands is remarkably varied!

Cardiff lies on Triassic rocks (206–248 Ma), which comprise mudstones, sandstones and conglomerates.

- (b) Nottingham sits on Carboniferous sedimentary rocks. As you travel towards London, you cross Triassic, Jurassic and Cretaceous rocks, and then the Tertiary rocks on which London lies; in other words, the rocks get younger towards the southeast. All these rocks are sedimentary, and include a wide variety of types, ranging from sandstones to limestones and clays; clearly, this part of the country was a site of deposition for a long time. You may have noticed that this sequence is not continuous — there are no Permian rocks, for instance, so there is a time break between the Carboniferous rocks and the Triassic rocks. This is an example of how to detect an unconformity from the map. You may also have included in your route the small blob of purple located just south of Nottingham. This represents the late Precambrian volcanic rocks of Charnwood Forest,

which include volcanic ashes, laid down in water, that contain examples of the Ediacaran fauna mentioned in Section 2.3; they are surrounded by younger sedimentary rocks.

(c) The early Palaeozoic rocks in the stratigraphic column (Cambrian, Ordovician and Silurian) are various shades of mauve. They occur mainly in southern Scotland (Ordovician and Silurian), NW Scotland (Cambrian), NE Ireland (Ordovician and Silurian), the Lake District (Ordovician and Silurian), Wales (Cambrian, Ordovician and Silurian), and SE Ireland (Cambrian, Ordovician and Silurian). You may have noticed smaller patches too — such as in western and central Ireland, the Isle of Man and Anglesey.

Some of these rocks outcrop in interesting patterns. The Ordovician and Silurian rocks of southern Scotland form distinct bands running from northeast to southwest, and these rocks continue with a similar trend across the Irish Sea into the north of Ireland. A similar NE–SW trend can be seen farther south in the early Palaeozoic rocks of Wales and in those south of Dublin, although they are not in such obvious bands in these areas. The significance of these patterns will be explained in Section 9.1.

(d) The oldest rocks are found along the coast and islands of NW Scotland (such as on the Isle of Lewis). They are of mid-Precambrian age (1 500–3 000 Ma), and are mainly gneisses.

(e) A line between these oldest rocks and Edinburgh crosses many different types and ages of rock. The sequence from northwest to southeast is roughly as follows: mid-Precambrian gneisses — Cambrian limestone — late Precambrian, Cambrian and Ordovician metamorphic rocks, with occasional intrusive igneous rocks (red) — Devonian strata — volcanic rocks — and finally Carboniferous strata, upon which some of Edinburgh stands. There are clearly several major time-breaks between adjacent rocks in this sequence. For instance, according to the key, between the Devonian and the late Precambrian, Cambrian and Ordovician metamorphic rocks there could be a time gap of over 600 Ma (i.e. 1 000–354 Ma), or as little as 26 Ma (i.e. 443–417 Ma). Establishing the age difference more accurately would depend on obtaining absolute ages for rocks on both sides of such boundaries. There are numerous igneous intrusions in northern Scotland; most of these are granites, and being intrusions, they are younger than the rocks they have intruded.

(f) Outside Scotland and northern Ireland, Devonian rocks are found in southern Ireland, southern Wales and southwest England (including Devon, as their name suggests). The approximate E–W trend of these Devonian rocks is very clear in southern Ireland where they alternate with Carboniferous rocks of similar trend.

Now that you've had a look at the geological map, and glimpsed the extent of the rock record in Britain, you should appreciate that rocks tend to be youngest in the southeast of Britain and generally become older to the west and north. Note particularly the broad, roughly parallel bands of Carboniferous, Permian, Mesozoic and Cenozoic strata crossing central, eastern and southern England. Older, Palaeozoic rocks outcrop at the surface in southwest and northern England, Wales, Ireland and southern Scotland. Farther north still, relationships between rocks of different ages become more complex, but in general it is true that rocks become older the farther northwest you travel.

Activity 9.2

The notebook pages that you used to record your observations for each site should provide a useful summary of the main features and their interpretation, and in the rest of Section 9.3 we shall show how this evidence can be used to piece together what was happening to southwest Britain during the Permian and Triassic Periods.

The techniques that we introduced in this activity are ones that are widely used by geologists in the field. It is often useful to start by getting a general, broad view of a locality, to see how the various parts are related. This can be followed by looking more closely at regions of interest, and by looking at hand specimens of the rocks. From the hand specimens you should try to identify particular rock characteristics (such as texture and minerals present), which in turn help to identify the rock type. You can then study the

exposure from a greater distance again, which often enables you to see additional features that were overlooked earlier. In practice, this is often an iterative process.

A field notebook is an essential item for any field trip, and this activity has demonstrated the sort of information that it is useful to record. A typical geologist's notebook will include both notes about the features observed and about their interpretation, and annotated sketches that illustrate particular features.

Task 1

Figure 9.2.2 shows a sketch based on the photo of the Dawlish cliff in Figure 9.2.1a. Note that the student who produced this sketch has correctly concentrated on the main features, including the bedding planes between the main beds of dune sandstones and the large-scale, high-angle cross-bedding within them. To save time, and to avoid unnecessary detail, only a few of the bedding planes have been drawn in, and these have been drawn as more-or-less continuous lines. The vertical feature near the centre is of little significance; it is merely a natural crack. Notice that the beds are not displaced across it (at least at this scale of view), so it is not a fault plane.

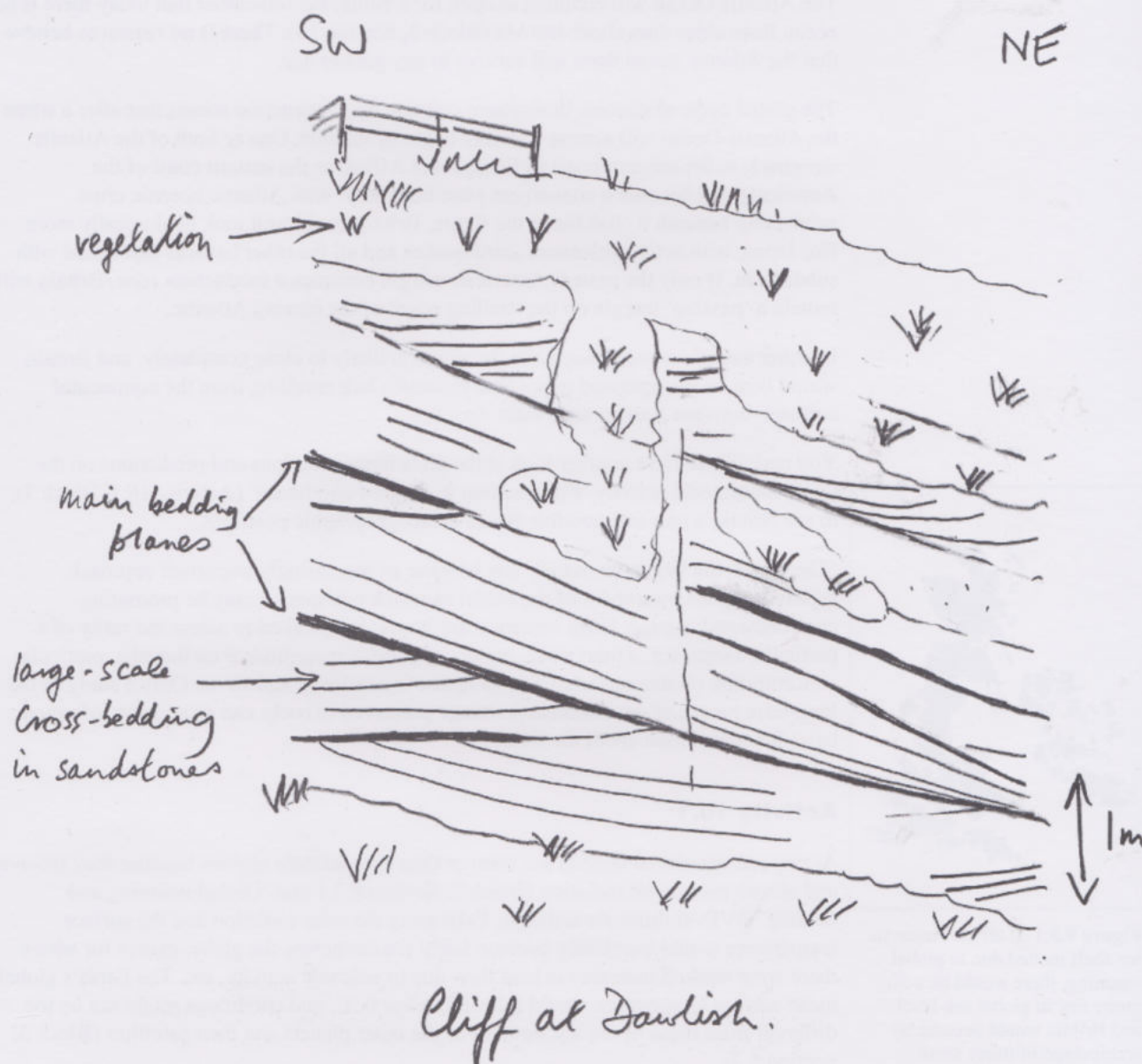


Figure 9.2.2 A sample sketch of the part of the cliff at Dawlish shown in Figure 9.2.1a.

Activity 9.3

Nobody can predict with certainty what the future holds for Britain in 100 000 years, let alone 100 Ma. We can only speculate on possible scenarios, and base these speculations on evidence of what has happened in the past and what we see happening now. What follows are the speculations of a member of the Course Team, but you may well have thought of additional points that are equally plausible.

In the nearer geological future, 100 000 years from now, the Earth may have entered another glacial phase of the Quaternary Ice Age in which much of Britain is buried beneath hundreds of metres of ice. Alternatively, global warming may have taken over (whether or not promoted by humans) — sea-levels may have risen, and substantial parts of lowland Britain may have become submerged (Figure 9.3.1). Conditions may have returned to the sub-tropical climate of the early to mid Tertiary. It is even conceivable that some time in the next 100 000 years the Earth may have been hit by a fairly large asteroid, causing many kinds of environmental change, as did the impact at the K–T boundary (Section 3.2.1).

The Atlantic Ocean will continue to open for a while, but remember that today there is no ocean floor older than about 180 Ma (Block 3, Section 16). There is no reason to believe that the Atlantic ocean floor will survive to any greater age.

The global cycle of oceanic lithosphere creation and destruction means that after a while the Atlantic Ocean will almost certainly begin to subduct. One or both of the Atlantic margins (i.e. the western coast of Europe and Africa, or the eastern coast of the Americas) will become a convergent plate boundary, with Atlantic oceanic crust subducting beneath it. 100 Ma in the future, Britain could well look geologically more like Japan, with active volcanoes, earthquakes and all the other hazards associated with subduction. If only the eastern American margin becomes a subduction zone, Britain will remain a 'passive' margin on the 'trailing edge' of the closing Atlantic.

In either case, however, eventually the ocean is likely to close completely, and Britain would then be incorporated into a new mountain belt resulting from the continental collision between Europe and North America.

You may like to have another look at the plate reconstructions and predictions on the DVD-multimedia activity 'Plate motion in the past and future' (Activity 16.1, Block 3), to see Britain's past and possible future palaeogeographic positions.

'The past is the key to the future' has become an increasingly important approach, especially given awareness of the extent to which our species may be promoting environmental change. Earth scientists are increasingly asked to assess the rarity of a particular event, e.g. a tidal wave, meteorite impact, magnitude 6 earthquake, particular concentration of atmospheric CO₂, 10 m rise in sea-level, and so on. Only a study of the long-term record of environmental change preserved in rocks can provide an informed basis for speculation about the future.



Figure 9.3.1 If all the Antarctic ice shelf melted due to global warming, there would be a 50 metre rise in global sea-level, and Britain would become an archipelago of many small islands.

Activity 10.1

At present, equatorial regions are warmer than high latitude regions because they receive and absorb more solar radiation (Block 2, Section 6.2.1 and 'Global warming and cooling' DVD-multimedia activity). Take away the solar radiation and the surface temperature would eventually become fairly similar across the globe, except for where there were marked increases in heat flow due to volcanic activity, etc. The Earth's global mean surface temperature would fall well below 0 °C, and conditions might not be too different from those of the icy surfaces of the outer planets and their satellites (Block 3, Section 5.2).

The notes below indicate some of the major points, but you may well have thought of others that are equally valid.

(a) There would be few effects on the solid Earth. Plate movements (Block 3) don't depend on energy from the Sun; sea-floor spreading, earthquakes, volcanoes, and mountain building would continue, though presumably with some minor differences due

to the prevalence of ice rather than liquid water. However, there would be major changes in the rates and patterns of weathering and erosion due to changes in the water cycle (Block 2, Section 7). The erosion of coasts by waves and currents, for example, would cease and, for a time, as the water cycle slowed down to its ultimate state in which precipitation was minimal, continental ice sheets and glaciers would be the main form of erosion. With the drop in temperature, chemical weathering would greatly slow down too (Section 6.2).

(b) Large-scale circulation of the atmosphere is driven by temperature differences between different parts of the Earth's surface (Block 3, Section 6.2.1). The lack of such temperature differences would mean no large-scale atmospheric circulation. Any circulation would be on a much smaller scale, driven mainly by local sites of heat emission such as volcanoes, with a minor influence from events that displace air, such as volcanic eruptions, landslides and so on.

(c) Surface ocean currents would diminish or cease entirely in the absence of the prevailing winds that drive these currents today. Deep ocean currents originate via freezing of seawater at high latitudes (Section 10.2.3); initially these currents might increase, as the Earth's surface cooled down and large volumes of seawater began to freeze. Eventually, the oceans would freeze over completely, and deep-ocean currents would all but cease. There would, however, continue to be some liquid water at mid-ocean ridges and hot spots.

(d) Nearly all life depends on sunlight for photosynthesis, either directly in the case of plants, or indirectly, in the case of herbivores that feed off plants, and carnivores that feed off herbivores (Block 4 'Ecological chains' DVD-multimedia activity). You could therefore have chosen virtually any animal species as one that would almost certainly not survive in the long term (though conceivably some species might evolve special adaptations to the new conditions). However, many of the animals that live in the deep ocean around the mineral-rich hot waters released at black smokers would very probably survive (Block 3 'Exploring the Mid-Atlantic Ridge' DVD-multimedia activity). Some extremophile micro-organisms (Section 10.4), including ones adapted to extreme heat and extreme cold, would survive — as would others that are manifestly independent of solar radiation (e.g. those that live in oil reservoirs).

Activity 10.2

Compare the marks that you awarded with those awarded by an S103 tutor.

Scientific content

The answer shows a good level of understanding of the topics set in the question. There is one omission in the account. Crystalline texture is also found in metamorphic rocks because new crystals grow in the solid state in response to increased heat and pressure, and are in competition for space with adjacent minerals. Igneous and metamorphic rocks can usually be distinguished on the basis of the presence or absence of mineral alignment.

There are two scientific errors. The speed of water downhill helps to determine its *kinetic* energy. However, the student understands the relationship between the grain size of a sedimentary rock and the energy of the depositional environment. The student states correctly that the grain size of a metamorphic rock is related to the metamorphic grade, and understands that grade is measured by temperature and burial depth (i.e. pressure). However, the answer also implies that grain size is related to rate of cooling. This is incorrect. Igneous rocks are intruded as magma, or extruded as lava, at temperatures very much hotter than their surroundings. Crystallization occurs as the molten rock cools to the temperature of its surroundings. Most metamorphism takes place because of an increase in heat and pressure, owing to deep burial. These conditions are maintained for as long as a rock remains buried at a particular depth, so no cooling is involved.

There is also one misconception. The student uses the term 'texture' to describe the roughness of a rock surface. This is not correct geological usage.

Awarded 15/19 marks for scientific content.

Rock types named

Appropriate examples have been named in the discussion of grain size, although it would have been helpful to name conglomerate as a coarse grained sedimentary rock. However, no rocks have been named in the discussion of texture.

Awarded 1½/3 marks for rock types.

Figures referenced

The references to Figures 5.1(b), 5.1(c) and Figure 7.4, are appropriate. Figure 5.1(a) should also have been included to illustrate crystalline texture with random orientation of the crystals found in igneous rocks. Figure 6.6 is not appropriate where it has been referenced because it does not tell us anything about the *energy* of depositional environments. However, it would have been appropriate if referenced when grain size in relation to water speed was being explained a little further on. Figure 7.1 could have been quoted to illustrate the concept of metamorphic grade.

Awarded 1½/3 marks for figure references.

Writing skills

Clarity: although there are no ambiguities in the answer, there are three spelling mistakes involving technical terms used in Block 10. 'Crystalline' and 'crystalized' should be 'crystal/line' and 'crystal/lized', rocks are 'coarse grained', not 'course grained' and 'larva' should be 'lava'. There is also one example of incorrect sentence construction: the sentence beginning 'Fine grained basalt rapidly' is incomplete as it does not contain a verb.

Conciseness: the answer is a little over-length, principally because it contains irrelevant information, i.e. the mention of layering in sedimentary rocks and relating texture to the roughness of a rock surface. There is also one sentence that is far too long. The sentence beginning 'If the grains in the rock only touch each other' should have been broken into several sentences. The sentence is also constructed clumsily.

Coherence: the answer flows logically and the division into two main paragraphs, each covering a different topic, is reasonable.

Awarded 3/5 marks for writing skills.

Overall mark awarded: 21/30

Do you think the marks that you and/or the tutor awarded were a fair assessment of the quality of the work?

A corrected version of the student's answer is given below, with corrected text and additions italicized. Irrelevant information has been scored through.

The texture of a rock is the way in which the grains are related to each other. In *crystalline* texture the crystals have grown into each other and this indicates that they have *crystallized either from a molten magma, or in a solid state*. If the crystals have all grown in different directions, i.e. they are randomly orientated *as in a basalt*, this means that they were able to grow unimpeded at first, another sign that they *crystallized from a molten magma (Figure 5.1(a))*. If platy minerals in the rock are lined up parallel to each other, *as in a schist*, the rock shows crystal alignment (Figure 5.1(b)). ~~this means~~ The minerals grew under pressure (Figure 7.4) and the rock is metamorphic. If the grains in the rock only touch each other, so that there are spaces in between (Figure 5.1(c)), *the rock has a fragmental texture. It is made up of an accumulation of rock or mineral fragments, or fossils (e.g. limestone) and is sedimentary as separate grains though* The spaces may contain cement that holds the grains together. ~~Sedimentary rocks usually show layering as well. Rocks that have a rough texture are usually coarse grained and rocks with a smooth texture are fine grained.~~

The grain size of an igneous rock shows how quickly it cooled. A *coarse* grained rock like granite cooled slowly, probably deep underground. Fine grained basalt *cooled rapidly, possibly as a lava flow at the surface*. The grain size of a sedimentary rock tells us about the energy of the environment in which it was deposited (~~Figure 6.5~~). The faster water flows down hill the more *kinetic* energy it has. *Coarse* grains are only deposited from fast flowing water (~~Figure 6.5~~) and so indicate a high energy environment, e.g. *conglomerate*. Fine grained sandstones are not deposited unless water flow is slow and so indicate a low energy environment. The grain size of a metamorphic rock shows the grade at which metamorphism occurred, i.e. the depth (*pressure*) and temperature (*Figure 7.1*). A *coarse* grained gneiss shows high grade metamorphism at 550 – 700 °C and 20 – 35 km depth ~~where it cooled slowly~~. A fine grained slate shows low grade metamorphism at 200 – 350 °C and only 5 – 10 km depth ~~where it cooled more quickly~~. (325 words, excluding figure references)

This was a difficult activity but it will have given you some insight into what your tutor has to do to mark your TMAs! It should also help you to look critically at your own TMA

answers, and improve them, before you send them to your tutor. Activity 10.3 gives you an opportunity to criticize your own writing.

Activity 10.3

You probably found it quite difficult to mark your own answer, though generally marking the scientific content is more straightforward than assessing the writing skills. In addition, most people find it harder to be critical of their own work than that of other people's. Being critical involves a lot more than saying 'it's hopeless' or 'it's brilliant'. You need to be able to take your work to pieces and to look at different aspects of the whole piece.

We gave you a mark scheme on this occasion, to help you to identify the sorts of things that a tutor would be looking for. When you write your answers to assignments you do not have the benefit of the mark scheme, but you should be able to work out a lot about what is required from the question. For example, it is clear that you must cover two aspects of the uses of fossils; how they can provide evidence of continental drift, and how they can be used to establish the biostratigraphic column. The second sentence of the question provides a hint that you should include the attributes that a fossil organism needs to make it useful for each purpose. Finally, you should look at the attributes of each of the examples given in relation to these attributes. The stated word limit gives you a hint about the amount of detail required.

It is worth trying to develop the habit of reviewing your answers and deciding what is good about them and what is bad about them, and then making changes where necessary before sending the TMA to your tutor.

Here is a **review checklist** that you can use, preferably a day or two after drafting an answer, so that you come to it afresh. Note that you weren't asked to include diagrams in your answer to part (a) of this activity.

- Have I answered the question set?
- Have I omitted any points, and is each point covered in sufficient depth?
- Is the material arranged logically, or would restructuring make the answer better?
- Have I included relevant diagrams (or formulae), and have I referred to them in the text?
- Is the meaning clear, and are my sentences complete? (Remember to try reading your answer aloud.)
- Are there any repetitions, irrelevant points or unnecessary words or phrases?

Here is an answer that contains all the relevant points. It would have been awarded full marks.

To provide evidence for continental drift, fossil organisms must indicate that continents that are now separated by oceans were once joined together. This means that they must be of the same species and age, and either land-dwelling or shallow-water organisms that would have been unable to migrate across an open ocean.

The biostratigraphic column is a sequence of zones, in order of age, with each zone characterized by particular fossil types. A zone fossil is a species that is used to characterize a particular zone. Ideally a zone fossil should be one where the species evolved rapidly so that it spanned a relatively narrow time range and is widespread geographically, as well as being abundant in numbers. It should also have a distinctive appearance.

Glossopteris was a land plant, and specimens are found in rocks of the same age on several different continents. As it would have been unable to cross oceans, it can be used as evidence for continental drift. However, as it was not marine, the chances of remains being buried and preserved are small and so fossil remains would not be sufficiently abundant for *Glossopteris* to be used as a zone fossil.

Ammonites were restricted to the Mesozoic Era and different species varied in appearance. They were fully marine and so fossils are likely to be abundant. These characteristics make them good zone fossils. However, because they were fully marine they were able to cross oceans and so fossil ammonites cannot be used as evidence for continental drift.

(251 words)

Activity 10.4

When answering this sort of question it is tempting to try to include everything you know about sediment deposition from the Devonian to the Cretaceous, rather than selecting only the information that is relevant to the assertion.

(a) The four key themes are given in the wording of the question:

- Plate tectonic activity and plate movement
- Changing climatic conditions
- Changing environments of transport and deposition
- Changes in the sediments and sedimentary rocks deposited.

As the initial emphasis is on plate tectonic activity and plate movement as influences of the types of sediment and sedimentary rock that were deposited, it is sensible to look first at how these factors have changed from the Devonian to the Cretaceous.

(b) You should have discovered that changes in plate tectonic activity also influenced depositional environments. Plate movement was responsible for the changes in climate experienced in Britain and, in turn, climate influenced the environments of transport and deposition. Your account will need to draw out these links and they will need to be reflected in your conclusion as well.

(c) Here is an example of a plan for the account.

Introduction (setting the scene)

Outline plate tectonic activity and plate movement across time.

Main body of account

Paragraph 1: Post-orogenic Britain land area – mountains source of sediment – sands, gravels etc., some river deposited. Use Figs 9.6 and 9.7. Periods of tectonic stability erosion flattens land – seas invade – limestones common, Fig. 9.10.

Paragraph 2: Opening of Atlantic – cycles of subsidence and sediment accumulation in Jurassic and Cretaceous.

Paragraphs 3 and 4: Plate movement leads to climatic change – hot desert (red sandstones) to warm tropical (limestones, deltas, swamps – also Section 6.3.3)) (paragraph 3). Return to hot desert, (red sandstones, evaporites, Fig. 9.6, Section 6.3.1) (paragraph 4)

Conclusion (summing up)

Influence of plate tectonics on sediments. Amend assertion to show plate tectonics influences environment, plate movement influences climate which influences environments and sediment types.

(d) We used the plan in (c) to write the following account. The sub-headings are included to help you to see how the account is divided. We would *not* expect you to include these sorts of sub-headings in your account.

Introduction

At the beginning of the Devonian, Britain was part of a continental land mass associated with the Caledonian Orogeny and the uplift of the Caledonian mountains in northern Britain, Wales and parts of Ireland. Tectonic stability then prevailed until the end of the Carboniferous when an ocean to the south of Britain closed, resulting in the Variscan Orogeny building mountains stretching across southern Ireland, south Wales and south-west England. Britain was now located within the super-continent of Pangaea, and again experienced tectonic stability until the end of the Triassic when Pangaea began to break up. Tectonic instability recommenced as the Atlantic Ocean opened up during the Jurassic and Cretaceous. Throughout this period of time, the plate on which Britain was located moved steadily northwards, from about 20° S during the Devonian to beyond 30° N in the Cretaceous.

Main body of account

Erosion of the Caledonian mountains produced large amounts of continental sandstones during the Devonian. Similarly, erosion of the Variscan mountains produced breccias, gravels and sands, or pebbly sands, during the Permian and Triassic, transported and deposited by rivers draining the highland areas (see Figures 9.6 and 9.7). During the

periods of tectonic stability that followed these orogenies, continued erosion of the mountains gradually flattened the landscape, and shallow seas were able to spread over the land surface. In the absence of land-derived sediments, limestones were able to accumulate, such as the coral-rich limestones of the early Carboniferous and the Coccolithophore-rich Chalk deposits of the late Cretaceous (see Figure 9.10).

The tectonic instability associated with the opening of the Atlantic during the Jurassic and early Cretaceous resulted in repeated cycles of crustal subsidence, followed by the infilling of the basins by water-lain sediments. During the Jurassic, localized subsidence and uplift produced marine basins that were infilled by muds and sands, and occasional accumulations of organic matter that generated oil and gas following deep burial. During the early Cretaceous, deposition took place in a large lake extending across south-east England.

The gradual northwards movement of the plate on which Britain was situated led to climate changes that are reflected in both the characteristics of the sediments and the environments in which they were deposited. The red sandstones of the Devonian were deposited in the hot (and probably arid or semi-arid) conditions that prevailed 20° S of the Equator. As Britain passed over the Equator during the Carboniferous, the warm tropical seas favoured the growth of corals and the formation of limestones (Section 6.3.3). The warm, wet tropical/equatorial climate led to sediment transport by rivers and the deposition of sands, silts and muds in large deltas that grew progressively out into the sea. As the sea became shallower, densely vegetated swamps developed. The remains of this vegetation were buried and compacted to form the Carboniferous coal deposits.

By the Permian, Britain was located at latitudes of about 10° to 20° S, similar to the position of the present-day Sahara desert. Desert conditions prevailed in Britain through to the end of the Triassic. Well-sorted and well-rounded wind-blown sands were deposited as sand dunes, farther away from the eroding highlands, during the Permian (Figure 9.6). These have the red colour typical of deposition in a hot, arid climate. Occasional temporary lakes that developed during the Triassic trapped wind-blown dusts, yielding red muds, and gypsum (an evaporite mineral) when the lakes dried out. Towards the end of the Permian, and again at the end of the Triassic, the sea invaded parts of Britain. Periodic desiccation in the hot, arid climate, resulted in cycles of mudstone, limestone and evaporite deposition in the Permian, and muddy limestones and evaporites at the end of the Triassic.

Conclusion

The original assertion implies that the influences of plate tectonic activity and plate movement on the types of sediment and sedimentary rock that are deposited operate independently of climatic and environmental influences. From this discussion it can be seen that these factors are closely linked. Plate tectonic activity (and intervening periods of tectonic stability) had some direct influence on the types of sediment that were deposited from the Devonian to the Cretaceous, but also had some influence on whether deposition took place predominantly in marine or continental environments. The influence of plate movement was indirect. Plate movement led to the changes in climate that influenced both the sedimentary environments available and the types of sediments that formed in them.

(711 words, excluding sub-headings and figure/section references)

Objectives for Block 10

The objectives state what you should understand and what you should be able to do after studying the block. The numbers of the questions and activities that test each objective are given in italics.

Science content

- 1 Explain the meaning of, and use correctly, all the terms printed in **bold** in the text.
- 2 Describe how organisms can become fossilized and, given appropriate information, assess the preservation potential of individual organisms or species. (*Questions 2.1, 2.2 and 3.1*)
- 3 Identify some common fossil groups, and interpret aspects of their biology and environment, using information from fossils and from associated sedimentary rocks. (*Question 2.3; Activities 2.1 and 3.1*)
- 4 Outline key events in the history of life from its origin in the early Precambrian through to the present day, placing the first appearance of major groups correctly in the geological time-scale of eons, eras and periods. (*Questions 2.5 and 3.2*)
- 5 Name the 'Big Five' mass extinctions, giving examples of their casualties, and outline evidence for the end-Cretaceous mass extinction and its possible causes. (*Section 3*)
- 6 Explain the use of fossils and strata in establishing a relative geological time-scale, and, given appropriate information, correlate rocks from different areas. (*Activity 3.2*)
- 7 Explain the relationship between crystals, minerals, and rocks. (*Activity 4.2*)
- 8 For the selected minerals listed in Table 4.2.1, outline the main differences between their crystal structures (e.g. chain silicate, framework silicate), and state their general chemical composition (e.g. silicate, carbonate). (*Activity 4.2*)
- 9 Describe how the internal, crystal structure of a mineral may give rise to particular properties observed in hand-specimens (such as cleavage, hardness, colour and crystal shape), and give examples of minerals for which these properties are particularly well developed. (*Activities 4.1 and 4.2*)
- 10 Describe the distinctive characteristics that can be used to identify, and deduce the origin of, selected common igneous, sedimentary and metamorphic rocks and their main constituents. (*Questions 5.2, 6.3 and 6.5; Activities 5.1, 6.1 and 7.1*)
- 11 Distinguish the main types of igneous rocks in terms of their mineral and chemical compositions; sedimentary rocks in terms of the size and nature of their grains; and metamorphic rocks in terms of their textures and mineral content. (*Question 5.3; Activities 5.2, 6.1 and 7.1*)
- 12 Explain how the texture and the constituents of igneous, sedimentary and metamorphic rocks are determined by their environment of formation, and how we use them to interpret the geological record. (*Questions 5.1 and 6.3; Activities 5.1, 6.2 and 7.2*)
- 13 Account for the diversity of magma compositions that is developed through partial melting and fractional crystallization processes, and explain why certain igneous rock types and associations of igneous rocks are found within particular tectonic settings. (*Question 5.5*)
- 14 Describe the basic principles of the main sedimentary processes operating at the Earth's surface, including the action of physical and chemical weathering, and the flow conditions that result in erosion, transportation and deposition of sedimentary material. (*Questions 6.1 and 6.2; Activity 6.2*)
- 15 Explain the processes of lithification (compaction and cementation), which transform sediments into sedimentary rocks. (*Question 6.5*)

- 16 Outline the conditions under which metamorphism occurs, and account for the differences in metamorphic rock textures and mineral content. (*Question 7.1; Activity 7.1*)
- 17 Explain how metamorphic belts are developed, and describe the links between lithospheric plate movement, mountain building, regional metamorphism and deformation. (*Question 7.4*)
- 18 Describe the effects of tensional and compressional forces on rocks. (*Questions 7.2 and 7.3*)
- 19 Explain how naturally occurring radioactivity is used to determine absolute ages of igneous rocks; given values of D/P and the half-life of the appropriate radioactive decay scheme, determine the absolute age of an igneous rock, and recall that all radiometric ages have an uncertainty associated with them. (*Activities 8.2 and 8.3*)
- 20 Deduce the relative ages of rocks from their field relationships, and explain how bracketing can give absolute ages of sedimentary rocks and their fossils. (*Activity 8.4*)
- 21 Summarise key events in the geological history of the British Isles during the Phanerozoic, incorporating, and interpreting, diverse evidence from rocks, fossils, geological structures and geological maps. (*Questions 9.1 and 9.2; Activities 9.1 and 9.2*)
- 22 Give examples of the long-term changes within, and connections between, the four Earth systems (solid Earth, hydrosphere, atmosphere and biosphere), including examples of what might happen to each if the Sun stopped shining. (*Activity 10.1*)
- 23 Explain how processes in the solid Earth can influence changes in global climate. (*Section 10*)
- 24 Account for the sources of sodium and chlorine in sea water, and explain why the salinity of the sea does not continually increase. (*Section 10*)

Science skills

- 25 Make observations on 3-dimensional specimens with the naked eye and with a hand-lens, and record those observations to scale in labelled drawings. (*Activities 2.1 and 3.1*)
- 26 Make observations on rocks that allow you to distinguish between igneous, sedimentary and metamorphic rock types, and recognize properties by which selected examples of each type of rock can be identified. (*Activities 5.1, 6.2, and 7.1*)
- 27 Make and record observations of rocks seen at different scales in the field, and make an annotated sketch of the geological features of a rock exposure. (*Activity 9.2*)
- 28 Use observations of fossils, rock specimens and strata, together with knowledge of modern organisms and geological processes, to make inferences about the biology and way of life of extinct organisms and about their ancient environments. (*Questions 6.3, 6.5 and 7.3; Activity 2.1, 3.1*)
- 29 Visualize two-dimensional representations of crystal structures as three-dimensional forms, and analyse complex three-dimensional mineral structures in terms of simpler structural components common to many minerals (such as the SiO_4 tetrahedron). (*Activities 4.1 and 4.2*)
- 30 Use maps or cross-sections to deduce the underlying three-dimensional geological features in an area, and thereby deduce the sequence of geological events that produced these features. (*Question 7.2; Activities 8.3, 8.4 and 9.1*)
- 31 Make scientifically plausible speculations concerning the distant future on the basis of evidence gained from the ancient past and from the present, and understand that speculation always has uncertainties associated with it. (*Activities 9.3 and 10.1*)
- 32 Plot graphs and histograms of tabulated data. (*Activities 6.2, 8.1 and 8.3*)
- 33 Determine the gradient of the best-fit straight line on a graph. (*Activity 8.1*)

Communicating science skills

- 34 Use a table to summarize the properties of a set of objects (minerals, rocks, etc.), and use a table of properties to identify objects, or to distinguish between objects, when their properties are known. (*Question 5.4; Activities 4.2 and 7.1*)
- 35 Produce labelled sketch diagrams, or descriptions in words, to record experimental observations, observations of specimens, and geological features observed in the field. (*Activities 2.1, 3.1, 6.1 and 9.2*)
- 36 Read information from graphs and histograms, and interpret this information. (*Questions 5.3 and 8.2; Activities 6.2, 8.1 and 8.3*)
- 37 Read and interpret information from maps. (*Activity 9.1*)

Mathematical skills

- 38 Calculate percentages. (*Question 2.4; Activity 6.2*)

Effective learning skills

- 39 Synthesise information from a variety of sources and from diverse scientific disciplines to answer particular questions. (*Activities 9.2, 10.1 and 10.2*)
- 40 Use DVD-based resources to discover information needed to answer questions. (*Activities 4.1 and 4.2*)
- 41 Revise material presented earlier in the course. (*Activity 5.3*)
- 42 Critically assess your own or someone else's answers to assignment questions for accuracy and style. (*Activities 10.2 and 10.3*)
- 43 Plan the content and organization of a long account. (*Activity 10.4*)

Appendix What to do if you are short of time

This brief guide to the activities in Block 10 should help you to decide for yourself whether you need to do a particular activity. Remember, though, that if you have the time you should aim to do *all* the activities in order to obtain the full benefit from your study.

The five numbered columns in the table below offer advice about each activity as follows:

- 1 essential that you do this activity at the particular point in Book 10 where it appears;
- 2 important, but there is more flexibility about when you do this activity, although you should try to complete it before moving onto the next section of Book 10;
- 3 may not be essential if you have some background already in the topic or skill, or have found earlier, similar activities straightforward;
- 4 could be left until later on, or dropped altogether if you are really short of time;
- 5 forms a useful tool to help you to revise concepts that you met earlier in the course that are built on in Block 10.

The last column on the right contains additional advice about some of the activities.

Block 10 activities

Activity	Category					Comments
	1	2	3	4	5	
2.1	✓					
3.1	✓					
3.2		✓				
4.1	✓					
4.2	✓					
5.1					✓	
5.2		✓				
5.3					✓	
6.1			✓			
6.2	✓					
7.1		✓				
7.2		✓				
8.1				✓		
8.2					✓	
8.3	✓					
8.4	✓					
9.1		✓				
9.2		✓				
9.3				✓		
10.1				✓		
10.2			✓			
10.3			✓			
10.4			✓			